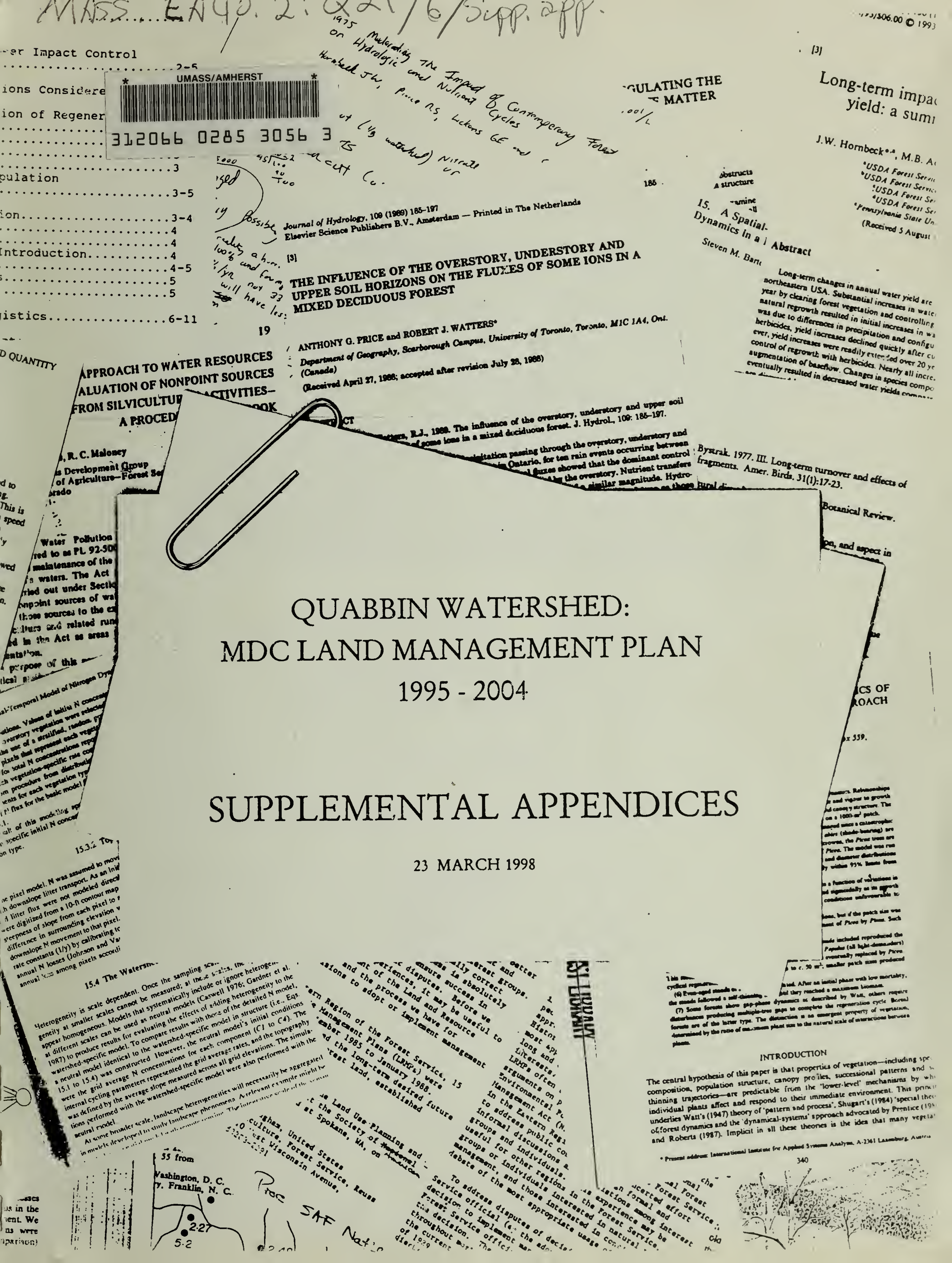
MASS. ENQ0. 2: Q2/6/Supp. app.

UMASS/AMHERST
312066 0285 3056 3



QUABBIN WATERSHED:
MDC LAND MANAGEMENT PLAN
1995 - 2004

SUPPLEMENTAL APPENDICES

23 MARCH 1998

Supplemental Appendices

QUABBIN WATERSHED:
MDC LAND MANAGEMENT PLAN

1995 - 2004

Commonwealth of Massachusetts

William F. Weld, Governor

Argeo Paul Cellucci, Lt. Governor

Executive Office of Environmental Affairs
Trudy Coxe, Secretary

Metropolitan District Commission
David B. Balfour, Jr., Commissioner

Division of Watershed Management
Joseph M. McGinn, Esq., Director

Principal Authors:

Robert O'Connor
Director, Natural Resources Section

Thom Kyker-Snowman
Natural Resources Specialist, Forestry

Paul Lyons
Natural Resources Specialist, Wildlife

Bruce Spencer
Chief Forester

July 11, 1995

TABLE OF CONTENTS

APPENDIX I. HISTORY OF QUABBIN FOREST AND WILDLIFE COMMUNITIES

A. QUABBIN FOREST 1
  1. Historical Perspective 1
  2. Impacts On the 20th Century Forest 7
B. HISTORY OF WILDLIFE 18
  1. Overview 18
  2. History of Selected Wildlife Species 19
  3. Management and Human Activities 21

APPENDIX II. WATERSHED MANAGEMENT LITERATURE REVIEW

A. WATERSHED COVER AND WATER QUALITY 24
B. FORESTS AND WATERSHED PROTECTION 27
C. REVIEW OF WATERSHED AND FOREST MANAGEMENT PLANS FOR NON-MDC AREAS 31
  1. Plan Organization/Contents: 31
  2. Goals/Objectives/Guidelines 32
  3. Unique Attributes/Ideas 33
D. FOREST MANAGEMENT SYSTEMS AND WATERSHED MANAGEMENT 34
  1. Silvicultural Systems and Their Value in Watershed Protection 34
  2. New England's Original Forests 44
E. FOREST MANAGEMENT SYSTEMS AND WATER 50
  1. Naturally-managed Forests 50
  2. Even-Aged Silviculture 55
  3. Uneven-Aged Silviculture 63
F. IMPACTS OF AIR POLLUTION UPON THE FORESTS AND WATERSHEDS OF THE NORTHEASTERN U.S. 66
  1. Acid Deposition 67
  2. Interaction Between Air Pollution and Forests 69
  3. Nitrogen Saturation 72
G. INSECT AND DISEASE IMPACTS 76

1. Introduction 76
2. Major forest types and effects of insects and disease 78

H. FOREST MANAGEMENT SYSTEMS AND IMPACTS ON WILDLIFE 82
1. Wildlife/Habitat Associations 82
2. Impacts of Management 86
I. WATERSHED MANAGEMENT AND GENERAL IMPACTS ON WILDLIFE 100
1. Impacts upon Biodiversity Given Various Management Systems 101
2. Impacts upon Forest Fragmentation and Forest Interior and Early Successional Species Given Various Management Systems 104
3. Wildlife Corridors and MDC Holdings 106
J. WILDLIFE IMPACTS ON WATER 107
1. Diseases 107
2. Indicator Bacteria 108
3. General Water Quality Parameters 108
4. Impacts on Watershed Cover 109
5. Impacts of Beaver on Water and Watershed Conditions 109
K. RELEVANT INFORMATION FROM QUABBIN AREA RESEARCH 118
1. Hydrology 118
2. Water Quality 120
3. Water Yields 122
4. Wetlands 123
5. Air Pollution 124
6. Relevance to Forest Management 124
L. RELEVANT INFORMATION FROM PAST QUABBIN WATERSHED MANAGEMENT 125
1. Silviculture 126
2. Water Yields 127
3. Best Management Practices 128
4. Fire 128
5. Forest Roads 129

APPENDIX III. WATERSHED FOREST MANAGEMENT AND UNEVEN-AGED SILVICULTURE . 130

APPENDIX IV. LAND PROTECTION FOR WACHUSETT, QUABBIN, WARE RIVER AND SUDBURY WATERSHEDS

A. LAND ACQUISITION PLAN FOR THE DECADE 136
 1. 1985-94 Land Acquisition Program Objectives and Accomplishments 136
 2. Land Acquisition Goals for 1995 and Beyond 139
 3. Decisions Between Acquisition or Watershed Protection Regulation ... 145
 4. Recommended Implementation Schedule for Land Acquisition and Associated Staffing/Consultant Costs 149
B. Boundary Encroachment Monitoring and Resolution 151

APPENDIX V. MDC LAND ACQUISITION PLAN, 1997-2007

A. PURPOSE OF MDC WATERSHED LAND ACQUISITION PROGRAM 154
 1. Protecting Water from the Impacts of Urbanization 154
 2. The Value of Forested Watershed Buffers 155
B. DESCRIBING SENSITIVE WATERSHED LAND 156
C. OVERVIEW OF MDC WATERSHED LAND ACQUISITION PROGRAM: 1985-97 ... 157
 1. Land Acquisition Report: 1987 158
 2. Land Acquisition Plan: 1991 160
D. LAND ACQUISITION PLAN: 1997 165
 1. Introduction 165
 2. Additional Techniques for Assessing and Protecting Watershed Land .. 171
 3. Applying Appropriate Layers of Protection 172
E. MDC CONSERVATION RESTRICTION POLICY 173
F. CRITERIA FOR UTILIZING FEE AND CONSERVATION RESTRICTION ACQUISITIONS 174

APPENDIX VI. EOEA ARTICLE 97 LAND DISPOSITION POLICY 176

APPENDIX VII: FOREST FIRE POLICY 179

APPENDIX VIII. GATE INSTALLATION /ROAD CLOSURES AND MAINTENANCE 186

A. ROAD CLOSURE AND GATE INSTALLATION 186

B. ROAD MAINTENANCE 187
C. WATER QUALITY CONSIDERATIONS ALL ROAD TYPES 189
D. LARGE CULVERT AND BRIDGE REPLACEMENT 190
E. GENERAL ROAD MAINTENANCE SCHEDULE 190

APPENDIX IX. REMOVAL OF NON-RENEWABLE RESOURCES

A. EXISTING REGULATIONS 192
B. PROHIBITION OF REMOVAL OF THE NON-RENEWABLE RESOURCES 192
C. POLICY FOR THE LIMITED REMOVAL OF NON-RENEWABLE RESOURCES 193

APPENDIX X. LOT REVIEWS FOR SILVICULTURAL TREATMENTS 195

APPENDIX XI. GREEN CERTIFICATION AT QUABBIN 196

LITERATURE CITED 201

APPENDIX I. HISTORY OF QUABBIN FOREST AND WILDLIFE COMMUNITIES

A. QUABBIN FOREST

1. Historical Perspective

Several cumulative references exist on the subject of historical New England forest ecology, including William Cronon's *Changes in the Land: Indians, Colonists, and the Ecology of New England*, Charles Carroll's *The Timber Economy of Puritan New England* and, for more recent history, Lloyd C. Irland's *Wildlands and Woodlots: The Story of New England's Forests.* Because agriculture had such a profound effect on the New England forest, Howard S. Russell's *A Long, Deep Furrow: Three Centuries of Farming in New England* is also pertinent. Two journal articles of particular interest are Gordon M. Day's "The Indian as an Ecological Factor in the Northeastern Forest" and "The Original Forest Types of Southern New England" by Stanley W. Bromley.

This material is reviewed below in order to suggest the composition and character of the past forests at Quabbin and the various disturbances which affected their development. For a more general discussion of the literature on "original" or "old-growth" forest, refer to Appendix II, below.

a. Impacts on the Forest, Pre-colonial to 1900

Through time two forces of change, often powerful and oppositional, have been at work in the forest: disturbance and successional reclamation. The current New England forest carries the imprint of changes ranging from major climatic shifts thousands of years ago, to the abandonment (and successional reclamation) of agricultural land within the past 150 years. There is considerable uncertainty as to what the actual "original forest" (here meaning pre-colonial) was like in the Quabbin region. However, considering the natural and human forces at work, a variety of forest conditions probably existed and trees of many ages and sizes were present. Overall species composition in the pre-colonial New England forest was likely similar to the present day with the exception of species since extirpated, eg. chestnut, or imported from other areas, eg. red pine. Nichols (1913) concluded that second growth and original southern New England forest stands had similar composition on moist sites protected from fire, but that second growth forests generally had a larger component of xerophytic species (more oaks and pine and less hemlock). Cronon's description of the descent of a single hillside in pre-colonial southern New England ranged from:

> ...a dry sunny forest of white and black oaks, white pine, and an occasional huckleberry or lowbush blueberry to a shaded valley...containing red oak, tulip poplar, hemlock, and beech with chestnut and black birch in between and red maple everywhere.

Nichols (1913) contains one of the best detailed descriptions of a large, original southern New England forest:

> For as in most virgin woodlands the stand here is of uneven age so that every stage in development and deterioration is present - from the slender saplings to the rotting logs with which the ground is strewn on all sides.

The distribution of size-classes of the pre-colonial forest would have been influenced greatly by the length of time since the last major weather disturbance, especially hurricanes, and the severity and magnitude of previous fires. Hurricanes disturb New England frequently, with catastrophic storms arriving, on average, every 100-150 years. Fires occurred naturally in the pre-colonial forest, but may have also been set by the Native American populations for a variety of reasons, including facilitation of hunting and clearing for agriculture. For example, Russell (1976) felt that the Brimfield-Monson area and the Ware River Valley were historical Native American hunting grounds, kept free of large trees and full of early-successional browse by set fires.

Fires, either naturally occurring or human-set would have varied in size and severity depending on the moisture content and amounts of fuel, weather conditions, soil moisture, topography and locations of wetlands, streams and rivers. This site diversity may, in part, explain the character of the early historic period forests which are described below. These descriptions are general to the New England area and do not describe the Swift River Valley specifically.

Bromley (1935) noted that early records of Europeans indicate that:

> ...the original forest was, in most places, extremely open and park like, due to the universal factor of fire, fostered by the original inhabitants to facilitate travel and hunting.

For example, Samuel de Champlain noted in 1605 that:

> The forests in the interior are very thin, although abounding in oaks, beeches, ashes and elms; in wet places there are many willows (Beggar 1922).

Conversely, other accounts of early explorers state that:

> We found a country full of very dense forests, composed of pines, cypresses and similar trees which grow in cold regions. (Giovanni da Verrazzano 1524 as cited in Wrath 1970).
>
> I saw nothing but great high cliffes of barren rocks, ouergrowne (sic) with wood... (John Smith 1614 as cited in Arben 1910).

Russell (1983) reviewed 35 pre-1700 historical records from the Northeast, including three were from Massachusetts. Six records contained descriptions of extensive burning by Native Americans and fourteen referred to the openness of the forests.

Bromley (1935) and Day (1953) felt that the population of Native Americans in pre-Colonial times was sufficient to burn large areas of forest frequently and that burning was a universal custom to keep forests open and produce browse for wildlife. Bromley also points out that in some cases deer modified the forest locally. He notes that larger trees occurred mainly in wetter woods, and that oak and pine forests were usually subjected to annual burnings, while beech and maple were commonly too wet to burn. Bromley felt that the prevalence of oak is partially due to the long history of fire. Russell (1983) felt that regular but infrequent fires accounts for the high amount of oak in the original forests.

Day cites the freedom of troop movements during King Phillip's War as another indication of the openness of the country. He quotes an 1831 description of Hatchet Lake Reservation in Southbridge, MA - one of the last areas influenced only by Native Americans and natural impacts:

> The vegetation of this section was characterized by an open forest of oak, pine, and hickory on the slopes, white pine and hemlock in the swamps, and bushy plains and blueberry barrens on the overly drained acid-soil plateaus and hill tops.

Some ecologists feel the impact of fires was great enough to have increased the oak-chestnut forest type significantly and effectively caused it to replace the northern hardwoods forest in interior sections of New England. Dwight (1821, as cited in Day 1953) noted that oak-chestnut forests of interior New England had probably been burned for over 1000 years. Thompson and Smith (n.d.) suggest that the effect of Native Americans was to create a "mosaic of seral stages, particularly in the areas surrounding village sites." The itinerant nature of the culture would have made these impacts more extensive, but less intensive; their impacts adding to the impacts of natural fires (Patterson and Sassaman 1988; Russell 1983). Carroll (1973) also emphasized the openness of the original forest. Thompson and Smith conclude:

> Rather than a land of dark and thick forest, the Indian's world was one of open woods and seral edge. Impenetrable forests were widespread on cold, moist slopes or wet depressions where ground fires were not likely to carry but these stands were discontinuous.

The fact that turkey, deer, and ruffed grouse flourished indicates an environment with edge. The decline of quail, which occurred in pre-settlement times, also indicates that regrowth of forest and fire suppression in modern times negatively impacted some species (Thompson and Smith n.d.). Thompson and Smith suggest that the demise of the heath hen (which disappeared from Massachusetts in 1840) was probably due to fire suppression after settlement, and that, in general, fire has been a key factor in the past abundance and distribution of New England wildlife.

However, while the conditions of much of the pre-colonial Southern New England forest may have been open and varied, this may be more related to natural events and conditions than the activities of Native Americans. Mahlstedt (1991, pers. comm.) feels that the mosaic, park-like condition of woodlands was related primarily to natural site conditions and disturbance regimes. He contends that human-set fires were not prevalent in pre-colonial times for the following reasons:

- the original explorers, the only Europeans to witness Native American culture first-hand, make little to no reference to a custom of setting fires;
- throughout prehistory Native Americans in Southern New England were semi-nomadic, and even when Europeans arrived there were no truely permanent settlements or villages;
- Native Americans moved seasonally and hunting occurred chiefly in the fall and winter when leave-fall minimized the impact of ground vegetation on overland travel;
- movement through the forests was relatively easy because Native Americans relied on following game paths;
- instead of drive hunting, which would have been facilitated by open fire-cleared woodlands, the local Native Americans hunted in small groups, tracking and stalking their prey, setting up blinds or using traps and snares, which was best accomplished with vegetated conditions.

Patterson and Sassaman (1988) summarize the argument for and against the impact of Native American burning, by noting that Russell (1983) discounts this practice, but admits that accidental fires may have added to the impact of natural fires, while Myers and Peroni (1983) stress the importance of purposeful fire setting. Botkin (1990) concludes that fire frequency of once per decade would be sufficient to favor oaks over maples and is consistent with the fire scars in the Hutcheson Memorial Forest in New Jersey.

Whatever their cause, disturbances likely stimulated successional reclamation and maintained a diversity of ages, sizes, and species in the early Quabbin forest. While stands of mature, mid to late successional species of great size are in the historical record, the pre-colonial Quabbin landscape was likely a patchwork of varying composition, given the record of disturbance (Cronon 1983). However, this mosaic, wrought by a variety of somewhat random disturbances, was forced into a simpler pattern by the arrival of the colonists, a population bent on agricultural development.

By the close of the 18th century, colonists had eliminated almost all of the "original" New England forest (Carroll 1973). At the peak of colonial development greater than 75% of the Massachusetts was cleared (Russell 1976), leaving only the steep and rocky sites and wetlands in tree cover. Land had been initially cleared for general agriculture, followed by a large expansion of clearings to support the rearing of sheep. The forest had supplied building material for homes and barns, fuel for cooking and heating, charcoal, and other forest products that provided income. Excess wood was burned to complete agricultural clearings.

Wood was also used for fences (stumps and later split-wood rails) but the colonists turned to another abundant resource, stone, for permanent fences. This back-breaking material was used for many purposes such as walls, foundations, dams, roads, wells, bridges, culverts, and to mark one's final resting place. Although the task of clearing the original forest with hand tools was formidable, it pales in comparison with the energy expended by humans and beast to wrestle stone from the ground and use it for the above mentioned purposes, especially given the numbers of miles of stone walls built. The lack of power tools and equipment limited the extent of the alterations to the landscape. The roads followed the topography and consequently are often narrow, winding and steep. Gravel was not used in abundance for road surfaces and when additional soil was required it was usually dug from roadside banks.

The clearing of land for agriculture was to some extent ordered by a perception of soil/tree cover relationships:

> Trees that required and maintained moist forest conditions, such as hickories, maples, ashes, and beeches, generally produced rich black humus beneath their fallen leaves, and settlers interpreted them as indicators of prime agricultural land. Oaks and chestnuts, with their denser undergrowth and more frequent groundfires, had thinner soils which required more work before they would produce favorable European crops. Still less desirable were the acidic and often

> sandy soils beneath various conifers - moist under hemlocks and spruces, dry under pitch and white pines - and colonial farmers avoided these wherever they could (Cronon 1983).

While these observations may have directed the colonists to first clear the most productive soils, ultimately as much as 80% of the central New England forest was cleared for some type of agriculture (Marchand 1987). In addition, the colonists took advantage of rich wetland soils. The wetlands water table was controlled through ditches and dikes and then used for hay, cranberries and in some cases for crops (Russell 1976).

b. Return of the Forest

As more and better land was open for settlement further west and as New England's hill farms became unproductive, marginal agricultural lands were abandoned. During the period between 1830 and 1865 farm land abandonment in New England occurred at an unprecedented pace, exacerbated by the Civil War's recruitment of young farmers from the region and by industrialization (Marchand 1987). For example, the Town of Petersham was estimated to be 15% forested in 1865, 48% in 1895, 55% in 1905 and 85% in 1976 (Patric and Gould 1976). The Quabbin forest, which was likely as much as 75% cleared land during the height of colonial agricultural development, would ultimately return to nearly 100% forest cover within 100 years time.

Much of this abandoned farmland would not be reclaimed by the same species composition which fills holes in a disturbed forest. Many of the abandoned fields had last been used either as pasture or to produce dwindling yields of hay, and so were in dense grass cover at the point of abandonment. This fact accounts for the emergence of white pine as a dominant forest type during the successional reclamation of these abandoned farms (Marchand 1987), a dominance which may be unique in the history of the area. White pine, and other conifers such as red cedar, are better able to invade and repopulate these grasslands for several reasons:

- the large numbers of relatively heavy wind-disseminated seed, which can work down through the sod to make contact with the soil,
- the presence of enough stored food in the seed to develop a seedling sufficiently large to compete with the grass,
- the drought resistance of conifer seedlings, which permits them to survive summer droughts occasioned by root competition with grass,
- the probable presence of inhibiting substances associated with the grasses

which retard growth of invading hardwoods,

- the ability of pines and their ectomycorrhizae to obtain nitrogen from the soil (Spurr and Barnes 1980).

The exception to the reclamation by white pine would have been the reforestation of fields which had been tilled right up to their abandonment. Because of the absence of grasses and the open exposure of the soil, successional reclamation would have included the broad spectrum of pioneer hardwoods on all except the very driest soils, where the drought-tolerant conifers may have still done better (Spurr and Barnes 1980).

2. Impacts On the 20th Century Forest

a. Early Cutting Practices

Early in the 20th century, as the white pine crop grew to merchantable size, the value of the standing pine trees increased dramatically (Marchand 1987). A lumber boom, aided by the steam- powered portable sawmill, resulted in the logging of 15 billion board feet of primarily white pine lumber from the central New England region, between 1895 and 1925. The trees were cut by hand, drawn out of the forest by horse, mule or oxen and milled on site. The sawn lumber was used for boxes, buckets, matches and building materials. This market could use a variety of lumber grades and therefore both high and low quality stands were in demand.

While the pasture and field pine were maturing, the future forest was developing in the understory. The understory composition would have varied depending upon the soils and aspect. Moist till soils on east and level aspects would have had hardwoods (chestnuts and oak) and hemlocks in the understory, while the pines, hemlock, and hardwoods would develop on the well-drained and moderately well-drained soils on the warm south and west aspects. The north aspects would have been dominated more by the shade tolerant hemlocks and hardwoods plus persistent oaks and chestnuts.

The heavy cutting at the turn of the century favored species that have an established tap root and sprouted vigorously after a disturbance, such as the oaks, hickories and chestnuts (Marchand 1987). Most other species were severely damaged by the intense logging activity and fires which followed in the dry slash. Although light-seeded species became reestablished, they could not compete with the rapid growth of advance regeneration of oaks, hickories and chestnuts. White birch seeded in after fire and became a component along with other birches and maples, but oaks eventually dominated the shorter-lived birches and maples. On well-drained upland soils advance oak, chestnut and hickory regeneration was generally in greater abundance than other hardwood species. Heavy cutting and fires caused vigorous sprouting of these species, eliminating hemlock and pine and resulting in a nearly pure hardwood forest. Similar to the conditions which preceded the establishment of white pine on abandoned farms, the heavy cutting and burning which established Quabbin's large, contiguous oak stands is not likely to be repeated.

The human impacts upon the New England forests over the past 300 years have had a dominating impact upon today's forests. For example, a 7,000 year history of a lowland forest in northern Petersham showed that eight major fires impacted it prior to colonization but in the past 225 years it was impacted by cutting ten times. The introduction of pathogens such as the chestnut blight has had an added impact. The impacts since colonization have made today's forests unique and different in composition and structure than those of pre-settlement times. It is possible that these changes may have long-lasting impacts upon forest soil processes (Foster 1992a,b).

b. Chestnut Blight

American Chestnut was a valuable and abundant hardwood tree in this region. This fast growing tree was normally associated with oaks and hickories. Chestnuts produced frequent seed crops that were important to both humans (food and cash crop) and animals. The trees grew tall with straight grain and therefore worked and split well. The wood was valued for barn and house frames, furniture, doors, fence posts, railroad ties (due to its rot resistance) and many other uses.

The chestnut blight (*Endothia parasitica*) was introduced around 1904 and within two decades had killed most of the mature chestnut trees in New England (Spurr and Barnes 1980). Chestnut had occupied a wide variety of sites and was a significant component of the forest. Because chestnut had so many uses and decayed slowly, most of the mortality was salvaged through extensive logging operations. The blight caused a thinning where chestnut was a major component and stimulated the growth of residual trees. As succession reclaimed the openings left by the dying chestnut, it was often simply replaced by its common associates in the stand; therefore, the oak-chestnut types were simplified to oak-hickory or oak types (Spurr and Barnes 1980).

The full impact on the forest ecosystem from the loss of chestnut is difficult to determine because it influenced so much of that ecosystem. Clearly, it had been an important food supply for wildlife (as well as man), a major component of the forest affecting both structural and species diversity, and a persistent competitor for light and space in the regenerative phase of forest development. The growth and development of the next forest will be different because of this loss. There is some hope that chestnut will make a comeback, as it has done in some areas, when the disease weakens or the tree becomes more resistant.

c. Gypsy Moth

The introduction of gypsy moth has had a significant impact on the Quabbin forest because these insects prefer oak leaves. The dominance of oak in this region has enabled gypsy moth caterpillars to defoliate most of the Quabbin during peak infestations, especially on hills covered with hardwood forest composed chiefly of oak. These are dry-site oak stands on sites more suited to pine. From these hill tops young caterpillars can be blown for many miles and result in widespread defoliation. Until recently, mortality from the gypsy moth had not been a major factor in the defoliated forest except to a developing understory of pine, to the less vigorous white, black and chestnut oaks and to scattered hemlocks within oak forests.

Although chemical control efforts were made in New England in the past, they have not controlled the increasing frequency of gypsy moths defoliations. Natural control is usually caused by a virus brought on through starvation in the later stages of defoliation in the second or third year of the cycle. A fungus that was released approximately 70 years ago to control gypsy moths is now devastating the caterpillars in early stages of their development, but only if certain humid conditions are present. More effective long-term control may result from the reduction of the oak forest especially on the well-drained upland pine sites and the development of younger age classes with a diversity of species.

The introduction of the gypsy moth has affected the growth and composition of the Quabbin forest. Mortality rates have been high in oaks and mixed-stand hemlocks in outbreak areas, and growth rates are greatly diminished during the years of defoliation for trees which survive. Advance understory regeneration of pine has been killed, representing many years of growth. Particularly susceptible trees such as white oak have been lost from large areas of mixed oak forest. It is unclear what the future of this impact will be, although it will likely depend to a large extent on the ability of natural defenses, perhaps including changes in species composition, to adapt to the presence of the gypsy moth. Mortality associated with infestations is of greatest concern on the Quabbin in oak stands where deer prevent regeneration.

d. Land Taking and Development for Water Supply

With signing of Chapter 321 of the Acts of 1927, the Quabbin Reservoir project had official approval to begin work. The bulk of the land purchasing in the Quabbin Reservation came with the "General Taking" of March 28, 1938. The "General Taking" is defined by the "fire line", a 40 foot clearcut swath along the MDC boundary. Besides land taking, the MDC was busy constructing dams, dikes, aqueducts, roads, highways, buildings, a power station, Quabbin tower, clearing the 24,000 acre reservoir and planting trees on 10,000 acres of open land. Most of this work was done in a period of 10 years. During this time, two major floods and a catastrophic hurricane occurred.

The clearing of 24,000 acres of all trees, and the subsequent flooding, impacted the Swift River Valley by eliminating most of the pine types, both white and pitch, all of the small ponds, miles of streams and significant wetlands. The clearing process created huge amounts of waste wood (slabs, branches etc.). This had to be removed and the only practical way was through burning. In the process of burning the debris, most of the present islands and hundreds of acres along the Reservoir shore and most of Quabbin Hill were extensively burned. These woodland fires stimulated the development of hardwood sprouts and seedlings throughout the burned areas. Tremendous amounts of deer food were produced by both the clearing and burning. Although the fires burned hot and killed small trees, they did not kill larger overstory trees. An exception was a later fire in 1957 which did kill the overstory. This fire was just north of Route 122 in New Salem and resulted in the death of 100 year old pines and hemlocks on 400 acres.

The construction of two large earth dams required huge amounts of soil. This resulted in the development of several open pit mines adjacent to the Reservoir and the stripping of 2-3 feet of top soil from most fields on MDC lands in the town of Ware. Most stripped areas were planted to conifers. These plantations have shown the impacts of soil loss with disease, stunted growth, and wind-throw.

During World War II, the military established a presence at Quabbin with a firing range at the south end of Little Quabbin and several bombing and strafing ranges for aircraft. Most of this activity had little impact on the land except for fires started by 100 lb. practice bombs. Many bombs ended up a considerable distance from the targets, and one of these managed to ignite a fire that burned 2,000 acres of the northeast corner of Prescott Peninsula. It was a hot ground fire fueled with blow-down from the 1938 hurricane. The fire crossed several roads before topography and wetlands stopped its spread. The fire opened the forest, fostering the production of an understory of hardwood sprouts and seedlings.

In the first years after it acquired lands, the MDC harvested forest products to provide for their lumber needs. A private sawmill owner could bid on sawing a certain amount of lumber from logs delivered to his sawmill. The sawmill would be set up near the forest where the trees were to be cut. During the late 1940's and through the 1950's at least four cuttings were made to meet these needs. In addition, several private timber sales were conducted in the 1950's both inside and outside gated areas of the Quabbin. Prior to 1960, the total volume of timber removed by these cutting operations (excluding hurricane salvage) was less then 5 million board feet.

e. Establishment and Management of Pine Plantations on Open Lands

A forestry program for the reforestation of open land and of areas growing brush and other undesirable species was initiated in 1934 for the better protection of the watershed, with the goal of establishing a revenue-producing watershed forest. Coniferous trees were chosen for the following benefits they produce:

- the prevention of the growth of deciduous trees so that leaves are kept from entering the water and undesirable color and taste produced by decomposing organic material is minimized,
- the reduction of the force of heavy rains through dispersal of rain drops into a fine spray by the coniferous foliage, thereby increasing the absorption of precipitation by the soil,
- the control of snowmelt in the Spring due to the dense shade beneath the coniferous canopy as opposed to the rapid melting and evaporation that takes place in open areas and in deciduous forests,
- the conservation of soil moisture in deeper soils due to the shallow rooting of conifers,
- the fast growth of coniferous trees and the value of the quality timber they produce, and
- the ability of conifers to grow well on a wide range of sites.

Red pine was specifically favored because it was resistant to blister rust and white pine weevil, was easily grown in the nursery, and survived transplanting well.

During the period from 1935 to 1946 approximately 8,243,600 pine trees were planted on roughly 6760 acres of open land. These areas consisted of:

Arable land - this land grew agricultural crops for human consumption or forage for feeding domestic animals. When agriculture declined much of this land was used as pastureland. The soils consist as fine sandy loams such as the Charlton series.

Pasture land - this is land on which domestic animals were pastured. This was open land, not pastured woodland. The majority of these soils were moderately well-drained fine sandy loams such as the Scituate series.

Sproutland - this land had dense shrubby vegetation or trees of seedling or sapling size. This land had recently (1 - 15 years) been withdrawn from agricultural use and was not cut-over woodland.

Of the 6760 acres originally planted, many failed, generally by succumbing to competition from other species. Plantations survived beyond the establishment stage on approximately 3200 acres.

Trees were planted in straight rows, mostly five feet on-center. This "five-by" spacing insured a rapid closing of the crowns in order to:

- prevent the development of large branches on the lower portions of the trees,
- produce straighter stems, and
- eliminate much of the danger of insect damage.

With this spacing, crown closure occurred within 15-20 years. At this point, these stands were to receive some kind of silvicultural treatment such as a thinning. This did not happen due to lack of labor and available markets and as a result of overcrowding and competition for water and nutrients, many stands became stagnated. The stands remained stagnated, except for a limited amount of commercial thinning in the late 1950's. During the 1960's approximately 630 acres of plantations were pruned and 730 acres received some type of pre-commercial thinning. In most instances, these operations were coincidental.

The decade of the 1970's saw a move from non-commercial to commercial silviculture, and thinnings occurred on about 800 acres of pine plantations. During this period the region experienced a drought and water quantity became a great concern. Ongoing studies on the Cadwell Creek experimental watershed and others showed that water yields could be increased by lowering the stocking of the forest and that greatest increases in yield occurred when the forest was completely removed. With water yields as the goal, approximately 400 acres of stagnated or diseased plantations were clear-cut and converted back into fields during the decade of the 1980's. This figure was considerably less than the 3,000 acres of plantation clearings which were outlined in the 1986 Forest Management Plan (the difference between the planned and actual removals was due to the need for careful supervision of private contractors and the limited number of available contractors).

During the 1980's, both intermediate and regeneration cuts continued, covering approximately 900 acres. While many of these plantations were on hardwood sites, white pine regenerated well in most instances but hardwood regeneration was very limited due to deer browsing. Toward the end of the decade, MDC management philosophy changed with respect to pine plantations, when water conservation measures proved successful and the need to increase water yields was no longer a primary concern. Today, MDC's principle concerns with its pine plantations are to maintain their ability to protect water quality, by increasing structural and species diversity and by replacing high risk stands (growing on wetter soils) through natural regeneration with native species more likely to persist on these sites.

f. 1938 Hurricane

This storm was a 100-150 year event that seriously damaged approximately 15,000 acres of the Quabbin forest, primarily on the east, southeast and south aspects. Level sites, northeast aspects and the upper slopes of north and northwest aspects were also damaged. The damage varied tremendously from nearly complete damage in older pine stands, to only a few trees in young hardwood stands. Many stands still contain tipped or downed trees more than 50 years after the storm. Pine rots slowly and in some areas of blow down, it is still difficult to walk through hurricane-affected stands.

A great effort was made to salvage the blow-down and several million board feet of the most accessible and best quality timber was salvaged by the MDC on Quabbin lands. Approximately 20 million board feet of primarily white pine was not salvaged. (Hunt, 1991, per. comm.) Even though large crews were sent into the woods to lop damaged trees, the pine remained a potential fire hazard for many years. Fortunately, in 1938 much of Quabbin was in hardwood tree cover of 10-40 years of age which was not seriously damaged by the hurricane.

1938 was a heavy white pine seed year. The hurricane spread this seed great distances and many young pine seedlings became established in the understory on well-drained upland. Other good pine sites, such as the kame terraces, also regenerated to white pine following damage to the pine overstory. Damaged pine stands on moist till soils regenerated to oak, ash, maple, birch, hemlock and scattered pine following the hurricane, whereas immature stands without advance regeneration regenerated to light-seeded hardwood species such as birch and maple.

g. Elimination of Access

Once gates and signs were put up in the 1940's, the public was not allowed access. Prior to this time the public had used the Quabbin lands for fishing, hunting and trapping. The concurrent impacts from clearing 24,000 acres, burning several thousand acres, and blow-down on 15,000 acres produced large amounts of deer browse. Coupled with hunting prohibition, this resulted in a large deer population that has seriously impacted the forest understory from the 1940's to the present.

The only exception to prohibited public access in the late 1940's was for shore fishing. A strong lobby prevailed over MDC's official objections to the program. Once walking access was allowed for fishing, public access for hiking gradually gained acceptance for all but the Prescott Peninsula.

b. Forest Management 1960-1990

The first "management plan" was actually a Master's thesis written by MDC Forester Fred M. Hunt in 1961 and titled "Forest Resources on the Metropolitan District Commission Lands Surrounding Quabbin Reservoir." The objectives of management outlined in this thesis were to:

- Provide, through Continuous Forest Inventory (CFI), detailed information on the condition of the forest so that the forest manager could carry out sound management practices designed to improve the productivity of the watershed for both water and timber values,

- Determine through a study of the literature on the subject, the types of vegetative cover which would best suit the needs of this particular watershed, and

- Develop, for each of the major timber types on the area, management procedures which would produce the types of cover determined above.

The recommendations necessary to meet these objectives were put forth in this document. The inventory, present condition of the forest, characteristics of good watershed cover and recommendations for watershed management were discussed in detail. Ideal forest conditions for the watershed were described as forest composed of native species which were long-lived and suited to the site conditions. White pine, red oak, hemlock and white ash best fit these criteria. The forest would be of moderate stocking, have good growth and quality and include equal areas in each age class. This forest would promote a forest floor that allowed precipitation to rapidly infiltrate the soil and would enhance both aesthetic and wildlife values.

The recommendations were to conduct commercial silvicultural operations on 10,560 acres and remove approximately 35 million board feet of timber. Much of this work would be salvaging trees that had been partially damaged by the 1938 hurricane or trees which were of poor health, vigor and quality. Several thousand acres of non-commercial silviculture was also recommended, primarily in dense pine plantations and hardwood stands that had regenerated from the 1938 hurricane. These cutting practices were designed to improve stand health and where possible allow regeneration to develop. Deer browsing was considered to be inhibiting forest regeneration on much of the reservation however (Hunt 1961).

The recommendations of the plan were closely followed and a total of 32.5 million board feet was harvested on approximately 9,000 acres of watershed. Although a few hundred acres of non-commercial silviculture was completed with MDC personnel, this work stopped in 1964 when the workforce was assigned to maintenance of the Quabbin Park area.

During this decade a significant drought occurred and the Quabbin Reservoir dropped 34 feet below full elevation, the lowest level since its construction. The role of forest management in defending against such dramatic drops became an important topic of discussion.

The first official MDC management plan was prepared by Bruce Spencer and Charles Walker in 1972 and titled "Watershed Management Plan for Metropolitan District Commission Lands Surrounding Quabbin Reservoir." The objectives of this plan were to:

- Create and maintain an additional water yield of 10% annually from the Quabbin Reservation,
- Improve the health and quality of the Quabbin forest,
- Maintain healthy populations of native wildlife, and
- Maintain, improve and protect an aesthetically pleasing landscape.

This plan followed and expanded upon most of the recommendations of Hunt's thesis. It also urged hiring more personnel to better care for the watershed. The condition of the forest was determined from inventory data collected from the remeasurement of several hundred permanent Continuous Forest Inventory plots (CFI). The implementation of silvicultural activities was detailed, especially commercial logging activities. Logging systems and methods to eliminate significant impacts to water, forest, wildlife and aesthetics were outlined. The watershed was zoned for forest management, administrative uses, and natural areas.

Deer still prevented regeneration on large areas of the watershed but the recommendation was to delay corrective action for 15-20 years, acknowledging that the absence of regeneration might enhance water yields. However, this plan stressed that a solution to heavy deer browsing be found at the end of that period, to compensate for the maturation and gradual break-up of the overstory.

Beaver, introduced in 1952, had spread throughout the entire watershed by 1972 and were responsible for creating approximately 1,200 acres of ponds and marsh. Although the damage to forests and road culverts from beaver were noted, the benefits to other wildlife were also mentioned. Beaver management was recommended only where the road system was threatened.

The plan recommended silvicultural operations on 12,000 acres of natural stands, thinning 3,000 acres of pine plantations and clearing 500 acres of stagnated and diseased pine plantations. Thirty one million board feet of timber was expected to come from these operations.

During the plan period, silviculture was conducted on 9,500 acres, yielding 20.5 million board feet of timber and 30 thousand cords of firewood. Approximately 75 acres of pine plantations were salvaged and cleared due to storm damage or disease. A new demand for firewood allowed thinning of overstocked stands that had been scheduled for work by MDC crews in the first plan. Only a small amount of thinning was done in pine plantations because there was little commercial demand for the wood and no budget to pay for non-commercial thinning. The difference between planned and completed work during this decade highlights the importance of market conditions in accomplishing necessary work.

The second MDC Quabbin Management Plan was prepared by Bruce Spencer and Paul Lyons in the early 1980's. The plan was titled "A Ten Year Forest and Wildlife Management Plan for the Quabbin Watershed." The objectives of this plan were:

- Identifying and protecting critical, sensitive, rare or otherwise valuable habitat,
- Thinning forest stands to reduce stocking levels to 20-40% (i.e. savannah forest) or 60-70% (i.e. "thinned forest"),
- Converting several thousand acres of conifer plantations to open grass cover,
- Planting important wildlife food/cover species, and
- Diversifying wildlife habitat conditions on the Reservation using a variety of other management practices.

These objectives supported the primary goal of increasing water yields while maintaining water quality and healthy forest and wildlife communities. The plan strongly supported the addition of more MDC personnel to better care for the watershed. The plan expanded the discussion on all aspects of management such as the landscape design aspects of watershed management, methods of determining the recommended harvest, and a discussion of the dynamics of water yields.

The goal of striving for multiple age classes of native species suited to site conditions was reiterated, although browsing and associated herbaceous competition had prevented and would continue to prevent the development of new age classes on 2/3 of the hardwood forest. The need for regeneration to replace the forest following a disturbance was again discussed.

Specific recommendations were made to work on 23,000 acres (20,000 acres of silvicultural practices and 3,000 acres of pine plantation conversions to fields) and harvest 33 million board feet, 150,000 cords and 400,000 tons of chips (red and white pine plantations).

The actual acreage worked was 11,450 acres from which 13.8 million board feet, 39,000 cords of firewood and 141,600 tons of whole tree chips were harvested. Of the 3,000 acres of pine plantations to be converted to fields, 400 acres were actually completed. Although the pines could have been marketed and MDC would have realized income from this project, contractors with the proper equipment were not available.

The firewood market collapsed in the last half of the decade and therefore much of the hardwood thinning was not completed. The creation of savannah forest via harvesting, which would then be maintained through deer browsing, was discontinued. It was felt that water-rich areas produced similar yields regardless of whether the vegetation was mostly ferns or trees.

Additional staff and equipment were added to better care for the watershed and maintain the roads and forest. The roads had been an erosion problem due to neglect. With a combination of new equipment and personnel plus monies from timber sales to supply gravel, trucking, culverts, gates and other equipment and supplies, much of the forest road mileage was restored to good condition. Equipment to operate within pine plantations while avoiding damage to walls and foundations was purchased for operation by MDC personnel. The purchase and installation of additional gates to control access has also been accomplished. Starting in the last half of this management period, an action plan to solve the deer problem was implemented.

The following is a tabulation of acres treated since the 1960's. A decline in acres treated in the 1980's is due to the decreasing ability of the forest to regenerate, changes in forest product markets, and the assignment of forestry staff to other projects including forest inventory, management plan preparation, boundary marking, and land acquisition.

Table 1: Acres of Silvicultural Treatments Fiscal Years
1980-1994

1960's	9,000	1986	1,169
1970's	9,500	1987	645
1980	2,202	1988	1,232
1981	1,037	1989	940
1982	1,831	1990	404
1983	1,598	1991	722
1984	1,369	1992	507
1985	1,512	1993	704

B. History of Wildlife

1. Overview

Within the geographic range of any wildlife species, its presence in a particular area is usually dependent upon the availability of suitable habitat. Thus, in the absence of empirical evidence concerning the composition of the historical wildlife communities in the Quabbin area, inferences about those communities can be made based on an understanding of the land use history in the region.

The history of land use in southern New England has resulted in dramatic changes in both habitat and wildlife communities. The pre-settlement landscape was mostly forest cover in varying successional stages due to the effects of natural disturbances and site conditions (Braun 1950), but with some grasslands (e.g., along the Ct. River) and open forests (e.g., resulting from beaver activity (Naiman et al. 1986) and natural and human-caused fire (Bromley 1935; Raup 1957; Day 1953). From the 17th to 19th centuries however, large-scale clearing for agriculture resulted in decline of forest cover and "forest" wildlife in favor of more "farm" and early-successional plant and animal species. Farm abandonment in the mid 1800's resulted in a gradual return to forested conditions and of forest wildlife.

Much of the abandoned farmland seeded in to white pine, and thus wildlife adapted to conifer cover did well during this period. When those pine stands were harvested in the early 1900's, the wildlife community responded accordingly - first with those species adapted to brushy and pole-stage growth, and later (continuing into the present) with species adapted to mature forest conditions.

In recent decades, widespread residential and industrial development has "carved up" significant portions of this forest cover, thereby restoring some of the early-successional conditions and wildlife that were once so common in the region.

The recent history at Quabbin has followed the general pattern described above with several exceptions. First, the creation of the Reservoir resulted in the loss of a significant portion of bottomland and over 40 miles of riverine, riparian and lacustrine habitat, while adding a new large lake with food and habitat for a variety of species. Secondly, no residential or industrial development has occurred (or will ever occur) at Quabbin. Thus, the Reservation now comprises one of the largest contiguous blocks of undeveloped, forested land in southern New England. These events have had substantial implications for the wildlife community. Indeed, these factors were instrumental in the successful return of both bald eagles and common loons to Massachusetts. Quabbin's lack of development and relatively unbroken forest cover is also important in providing habitat for a number of "forest interior" species.

In addition to the above general trends, Quabbin's habitat and wildlife community have been altered over the years by a number of other natural and human-caused events. Some of the more important impacts have been: the 1938 hurricane, periodic fires, gypsy moth defoliations, impacts of a growing deer population, re-establishment of beaver, and MDC management activities (from plantation establishment to recent forest management).

2. History of Selected Wildlife Species

With the exception of extirpated species, most indigenous wildlife have been present here for centuries, although their relative abundances have changed in response to various factors (e.g., prevailing land-use patterns, successional stage of habitat, catastrophic events, predation, etc.). Thus, the overall composition of Quabbin's wildlife community has probably changed little over the years, with a few notable exceptions.

Certain species were not able to withstand the changes they were exposed to and were lost to the region (for example, wolves, mountain lions, beaver, eagles, loons) or to the world (e.g., passenger pigeons). Some of these have become re-established in the state however, either with human assistance (e.g., bald eagles, wild turkeys) or on their own (e.g., common loons). Others have not re-established themselves, and may never be able to make come-backs (e.g., mountain lions, Eastern woodland caribou). Still other species have gradually expanded their ranges to include central Massachusetts (e.g., coyotes, nesting Cerulean Warblers and Common Ravens).

Several species are notable because of the significant impacts they have had on both habitat and other wildlife. Examples include beaver, deer and coyotes, as well as a variety of smaller species.

Beaver were completely extirpated from Mass. by the early 1700's and did not return for

250 years. Their absence had a dramatic influence on riparian habitats - these areas became predominately wooded, whereas in earlier times, most small streams with beaver present contained numerous reaches with open canopy (Naiman et al. 1988). Following their return to Quabbin in the early 1950's, the beaver population experienced a period of rapid growth, followed by a dramatic decline, and a recent levelling off at a density much lower than their peak density. During this time, beaver have re-occupied virtually all of the suitable drainages at Quabbin, and converted many of these stream valleys to a more open condition. This has had a substantial impact (both positive and negative) on other wildlife, habitat conditions and hydrology. Beaver activity represents one of the most significant natural impacts on the watershed environment and the nature and implications of these impacts are discussed more fully in Section III.F. of the main Quabbin Land Management Plan.

Quabbin's white-tailed deer population has also undergone and caused some significant changes during the past century. Early settler accounts suggest that deer were abundant during the 1600's, and they undoubtedly influenced habitat conditions during that time. By the mid 1800's however, unregulated killing, along with the effects of land use changes, made deer sightings rare in this region. In Massachusetts, deer hunting was prohibited from 1898 to 1910, so by the time Quabbin was established, the population had probably grown to moderate levels. Hunting was prohibited on the newly-established Quabbin Reservation starting in 1938.

With the desirable habitat conditions, the absence of large predators, and the prohibition on hunting, it is likely that the herd responded with virtually uncontrolled growth. By the late 1940's, state officials and researchers (e.g. Jones 1951) were beginning to note the dramatic effects that the deer herd was having on forest regeneration. As is typical in unexploited deer populations, it is likely that the herd exceeded the carrying capacity of the habitat during that time period, and experienced substantial mortality. It probably then rebounded to a point where an equilibrium state was achieved between deer numbers and food supplies. Such equilibrium states have been documented in a number of situations involving ungulate populations (Caughley 1981).

In recent years, deer were still numerous on many parts of the Reservation, and impacts on forest regeneration continued, despite the influence that a growing coyote population had on the herd. The impact of deer on regeneration has been well-documented recently and has resulted in the adoption of a deer control program for the Reservation.

Eastern coyotes are another relatively recent addition to Quabbin's wildlife community, and have been of significant public interest since their arrival in the region in the early 1970's. Accurate data on coyote population growth is not available, but various indices (e.g., frequency of sightings, results of recent surveys) suggest that coyote numbers increased significantly in the mid 1980's. Coyote sightings and sign are now recorded from all parts of the Reservation. Results of recent census efforts suggest that coyote numbers have stabilized somewhat at Quabbin. As a major and highly adaptable predator, their presence has undoubtedly altered the nature of predator/prey relationships in Quabbin's wildlife community in recent years.

Other species also influence habitat or other wildlife, although less so than the above species. For example, porcupines can have significant local impacts on hemlock, sugar maple, and other tree species; small mammal activity can have substantial impacts on tree roots, acorn and other seed survival and germination, seedling growth, gypsy moth numbers, and even the integrity of dams and dikes; salamanders may comprise a significant portion of total faunal biomass, and may play an important role in the processing and cycling of organic materials that affect ecosystem stability and function.

3. Management and Human Activities

Quabbin's wildlife community has been impacted in a variety of ways by management and other human activities. While actual data are unavailable, various generalizations can be drawn .

Human activities involving direct control on Quabbin's wildlife community have been uncommon since its creation in the 1930's. Except for recent controlled deer hunts, public hunting and trapping have never been allowed on the Reservation, although periodic "takings" of wildlife have occurred. For example, a review of early correspondence in MDC files indicated that:

- there were early efforts to "exterminate wildcats" on the Reservation;
- permission was granted to the Massachusetts Division of Fisheries and Game (MDFG) to box-trap hares and rabbits in 1947;
- porcupine trapping occurred in the 1950's; and
- the MDFG authorized MDC to destroy beaver doing damage in 1970.

A variety of wildlife research projects have been conducted on the Reservation, since the mid-1940's. These projects included studies on deer, woodcock, ruffed grouse, wild turkey, otter, hare, porcupines and beaver. For the most part, these studies had minimal impacts on the wildlife community, although several studies on beaver population control through sterilization in the 1970's, may have slowed the growth of that population during those years (Kennelly and Lyons 1983).

MDC management activities and decisions have impacted wildlife in a variety of ways during the history of the Reservation. In the early years, the establishment of conifer cover on 3,200 acres of openland probably resulted in further declines in early-successional wildlife species. The prohibition of hunting and trapping likely had profound influences on both the population dynamics of game species, and in later years, on habitat conditions (as the growing deer population exerted more and more influence on vegetation conditions).

Active forest management on Quabbin began in the 1960's, and this resulted in a variety of impacts on the wildlife community. The impacts of forest management activities on wildlife are discussed more fully in Appendix II, Section H. and in Section V. C. of the Quabbin Land Management Plan.

Wildlife considerations have been included in all MDC Forest management plans to date, and the wildlife component of those plans has undergone substantial evolution since the first plan was prepared in the early 1960's. In that plan (Hunt 1961), discussion of wildlife management was largely restricted to the control of deer, beaver and porcupine damage to trees. In the next plan, Spencer and Walker (1972) considered wildlife to be a valuable component of the total Quabbin environment, and developed a plan that addressed both the impacts of wildlife on the watershed and the impacts of forest management activities on wildlife.

MDC hired its first Wildlife Biologist in the early 1980's, so the wildlife sections in the next management plan (Spencer and Lyons 1986) was more detailed than in earlier plans. The 1986 plan continued the general approach of the 1972 plan - i.e., it recognized the relationship between wildlife and forest management - but broadened it further to incorporate consideration of water quality and quantity and forest conditions and wildlife. The wildlife section of that plan had three main components:

- identification and protection of critical or key wildlife areas,

- wildlife habitat planning, using a "featured species" approach, and

- miscellaneous wildlife enhancement or impact control activities.

With the development of the current plan, the focus of wildlife management at Quabbin has become even more focused. The renewed emphasis on protection of water quality that has guided all watershed management activities in recent years, also provides the basis for the wildlife portion of the current plan. Identification and protection of rare species and habitats is still an important goal, but general wildlife habitat planning and development receives less attention in the current plan. Instead, habitat conditions on most sites are determined by watershed protection considerations and specific site conditions (e.g., soils, aspect, etc.). Therefore, the composition of the wildlife community will be largely dictated by the watershed cover goals, and the progress and timing in achieving them. Consequently, rather than establishing habitat goals which forest management would then work to achieve, this plan will assess the likely impacts of the planned forest management on the wildlife community.

Greater focus on direct wildlife-water quality relationships will also be evident in the current plan. This fits with the theme of water quality protection that is woven throughout the plan and newly promulgated federal and state drinking water regulations.

APPENDIX II. WATERSHED MANAGEMENT LITERATURE REVIEW

A. WATERSHED COVER AND WATER QUALITY

The first question that must be addressed in the MDC Watershed Land Management Plans is: what type of watershed cover best protects and enhances water quality? Several studies of watersheds indicate that forest cover provides the best protection for water quality (Carlton 1990; MDC 1989; Dunne and Leopold 1978). Briggs and Ficke (1977), examined sediment data for 18 large watersheds across the U.S. (9 predominantly forested, 9 heavily influenced by non-forest land use), and found that forested watersheds had significantly lower sediment concentrations. MDC studies of five small tributaries to the Wachusett Reservoir also indicate that as the percentage of non-forest and developed area increases, water quality decreases (O'Gara 1989a and 1989b; Rondeau 1989; Rondeau and O'Gara 1990). Although it is difficult to outline the contribution to various water quality parameters of different land uses, it is clear that urban, suburban, and agricultural land uses all contribute in some way to lowered water quality. Forest cover is also superior to undeveloped open land in protection of water quality, due to higher infiltration capacities, reduced overland flows, reduced storm flows, and increased nutrient usage (Carlton 1990).

Within MDC lands, land use options are limited by the Division's mandate for water supply protection. Development of MDC lands for urban/suburban uses is not considered. However, removal of lands from forest cover has been done in limited amounts for the purposes of recreation, water yield increases, power utilities, wildlife management, low intensity agriculture, and aesthetics. In addition, a portion of the newly acquired lands have a long history of agricultural use and decisions on their future management are part of this plan.

While this plan focuses upon forest and wildlife management, recreational usages which take land out of forests must be considered. Studies show that recreational impacts upon water quality include the introduction of pathogens and soil erosion (see O'Connor and Zilligen 1996 for a literature review). One of the largest impacts is unregulated use of poorly-located access roads. Kochenderfer et al. (1987) compared forested, past agricultural, and recreational use watersheds and found the highest sediment yield coming from the watershed which had unregulated use of poorly located woods roads for recreation and timber harvesting. In the study of recreational impacts at Ware River watershed completed in 1988 by MDC, unregulated road use and off-road use of all-terrain vehicles were MDC's chief concerns.

All four MDC watersheds are crossed by power utility rights of way (electric, gas, and telephone). Impacts from this use include construction and maintenance which remove forest cover and expose mineral soils. MDC has also documented erosion problems on utility rights of way which were used by all-terrain vehicles at Ware River. More recently, this type of erosion problem is occurring at the Quabbin watershed as well. Rothacher (1970) specifically mentions powerline rights of way as a problem for watershed management.

Studies point to decreased water quality from agricultural activities. For example, Kochenderfer et al. (1987) compared a forested watershed with one which had been heavily farmed 50 years ago and found the forested watershed had a sediment yield of 31 lb/acre/year while the former agricultural watershed yielded 253 lb/acre/year. The authors stated that the sediment coming from the former agricultural watershed was from sites which continued to erode. The average sediment load from agricultural watersheds is 4,000-10,000 lb/acre/year (Patric, Evans, & Helvey 1984). The actual sediment input from agriculture is linked with the types of "best management practices" used. Beyond the impacts of poor agricultural practices, Van Miegroet and Johnson (1993) list the following attributes of forests which make them superior to agricultural cover in protecting water supplies:

- differential rooting patterns and depths
- variation in annual return of organic matter and nutrients from canopy
- periodic tree mortality
- accumulation of forest floor organic matter
- periodicities in above and below ground processes
- temporal and spacial heterogeneity in soil properties

Robinson et al. (1979) noted that wooded headwater streams were more effective in denitrifying waters and recommended keeping headwaters in forest cover, instead of agricultural or developed usages.

Within the field of watershed management, there is an emerging interest in "cumulative watershed effects analysis" (Cobourn 1989). This concept is based upon the premise that cumulative effects of separate activities in a watershed can cause water quality damage. This concept focuses chiefly upon non-point source pollution. This type of pollution is also of increasing concern to MDC. Cumulative watershed effects analysis looks at all activities and land uses which may affect a watershed and weights their impact by the type of use and the sensitivity of the land. For MDC lands, cumulative impacts of recreation, forestry, wildlife, natural disturbances (fire, wind, ice, insect, diseases), and maintenance of open lands would be involved.

While water degradation from non-forested land use has been documented, impacts often relate to inappropriate or unregulated activities which cause erosion, urban runoff, or other measurable pollution. In assessing the long term impact of deer browsing at Quabbin, MDC looked at the potential water quality of herbaceous (non-agricultural) watersheds versus forested watersheds. Carlton's review (1990) contains perhaps the most extensive survey of this topic available.

Carlton examined several studies which compared grass and shrub watersheds with forested watersheds. Each study showed higher concentrations of nutrients and certain ions flowing from watersheds with primarily herbaceous cover. A comparative study of a prairie and forested watershed in Minnesota showed significant differences in the water flowing from the two watersheds (Timmons et al, 1977). Growing season losses of all elements measured, as well as many other water quality parameters, were greater on the prairie watershed. This occurred even though the forested watershed received more precipitation (especially snowfall) and had an average slope of nearly five times that of the prairie watershed.

Timmons et al (1977) and other studies show that there is a basic hydrologic difference between forested and non-forested watersheds. In forested watersheds high infiltration capacities preclude most overland flow of water and a great deal of the nutrient capital is locked into the forest vegetation and the thick layer of organic matter on the top layer of the soil (a more detailed examination of the hydrology of forested systems is contained in section E. below).

In herbaceous watersheds, due to a much reduced organic soil layer and increased runoff, a much higher percentage of runoff occurs as "quickflow" - either overland flow or rapid subsurface flow. The slower flow of precipitation through forested soils results in a less turbid water lower in dissolved substances eventually reaching the tributaries. The forest hydrologic process tends to reduce the leaching of nutrients (especially nitrates) and buffers the effects of acid rain. For example, Lee and Weber (1982) found that a hardwood forest canopy considerably enriched throughfall precipitation with calcium, magnesium, and potassium. Additional neutralization of precipitation occurred as water percolated through the upper litter layer of the forest. Art and Dethier (1986) also note that the chemistry of waters reaching stream channels is strongly dependent upon the path by which it arrived (surface versus subsurface flow).

Sweeney (1993) compared the physical characteristics of headwater streams with second growth forest and grass cover in Pennsylvania. He reported that the stream channels of headwater streams with forest cover were approximately 2.5 times wider than those with grass cover. The narrowing of stream channels with grass cover was caused by the slumping of grass sod from the banks into the stream channel, making it narrower and deeper. In addition, the forested streams had 7.5 times as much woody debris and 27 times as much snag volume in channels compared with streams surrounded by grassy meadow. Bormann, Likens, & Eaton (1969) reported that in a forested watershed in New Hampshire, debris pools caused by dead and downed forest matter occurred every 1-3 meters and could serve to slow the movement of suspended material and reduce the erodibility of the watersheds.

The above findings clearly indicate that, in general, forested land yields higher quality water than non-forested land. The next section will examine more closely the elements of forests which aid most in watershed protection. Later sections review specific approaches to the management of forests and their impact upon watershed protection.

B. FORESTS AND WATERSHED PROTECTION

While Section A above evaluated various types of land uses and cover types as they relate to watershed protection, this section will examine attributes of forests maintained for watershed protection. This section will describe processes that occur in most forests. More detailed examination of the impacts of disturbance (both natural and forest management) and the watershed protection value of various forest types and successional stages will be examined in section E. below.

The study of forest hydrology involves different concepts and processes than traditional engineering hydrology. Most engineering hydrology models are based on Horton's "overland" flow concept which assumes that most of the runoff from watersheds flows over the land surface in a uniform way (Dunne and Leopold 1978; Hewlett and Nutter 1970). These models are effective in describing urban/suburban and agricultural lands, but do not accurately describe small upland, forested watersheds.

The Hewlett "variable source" model takes into account the large infiltration capacity and the lack of overland flow that characterizes forest systems (Hewlett and Nutter 1970). During storm events, this model assumes that the bulk of stormflow occurs as subsurface "translatory" flow, and thus enters tributaries slowly when compared to overland flow. For example, the average distance from a perennial channel to the watershed divide in the East is 600 feet. This distance is covered in ten minutes with overland flow versus several months with subsurface stormflow. This contrasts to normal forest non-storm flow which slowly percolates to groundwater before eventually entering a tributary; an even slower process (Hewlett and Nutter 1970; Whipkey 1970). Due to this slow infiltration and subsurface flow process (even during most storms), forest watersheds maximize the contact time of water with the soil - thus allowing further neutralization and filtration of water before entering tributaries. Overland flow involves little soil-water contact time and can also be problematic in that soil erosion and higher storm flows (often associated with channel erosion) can occur (Pierce 1965).

Several studies indicate that the ability of forest soils to accept incoming precipitation greatly exceeds even 100 year storm events (Patric 1976). For example, Lull (1965) (as cited in More and Sopper 1990), states the infiltration rate for southern New England soils greatly exceeds the 100 year intensity 30 minute storm of 4-5 inches per hour. However, in large, extended storms there may be limited overland flow in forests. This is not due to the ability of water to infiltrate the soil, but to the overall capacity of the entire soil to hold water being exceeded. For example, Lull and Reinhart (1972) estimate soil water-holding capacity in the northeast to be in the range of 1.5-2.5 inches of water. In these instances, overland flow may occur over brief distances, with infiltration usually occurring before tributaries are reached due to the number of obstacles in a forest, such as logs, rocks, and branches (Pierce 1965).

Very thick litter layers may not appreciably reduce overland flow because the actual infiltration into the soil through the litter layer is not the limiting factor in large storms (Pierce 1965). However, forest soil humus can hold .8 of an inch of water, which increases the overall water holding capacity of the soil (Lull and Reinhart 1972). While it has been speculated that winter overland flow occurs due to concrete frost, this condition occurs only sporadically in the northeast and does not appreciably add to overland flow (Lull and Reinhart 1972) .

Forest soils are protected from sheet and gully erosion due to several factors including:

- lack of overland flow of runoff
- protection of erodible mineral soil by a thick layer of organic material
- water-holding capacity of the large amount of organic material mixed into upper soil levels
- reduction of raindrop energy from forest canopy layers and understory vegetation
- reduction of amount of precipitation reaching the ground due to interception by vegetation (accounts for 2-6% of flood-producing rainfall and 5 inches of the 40-45 inches of annual precipitation in the eastern U.S.)
- increased soil storage due to growing season evapotranspiration water losses (accounts for 18 inches of the 40-45 inches of annual precipitation in the eastern U.S.)
- reduced flood peaks due to streamside forest vegetation

(Dyrness 1965; Hewlett and Nutter 1969; Lull and Reinhart 1972; O'Connor 1982b; Patric 1977; Robinson et al. 1979).

Therefore, many of the basic soil-erosion models prepared for agricultural soils (such as universal soil loss equation of Wishmeier and Smith 1960) are only applicable to areas within a forest where mineral soil has been exposed or compacted such as woods roads and skid roads or large scale blowdown.

Mass movement erosion (landslide) is the largest contributor to stream sedimentation in the Pacific Northwest and is an important factor in mountainous areas of the northeast (Brown 1972; Rice et al. 1972; Eschner and Patric 1982). While not a common event on the gentler topography at Quabbin, Bormann et al. (1969) note that disturbances (fire and wind) which destroy biotic stability could lead to greatly increased losses to mass movement. Hurricanes would be likely to cause significant erosion only if mass wasting occurred, as appeared to be the case at Shenandoah National Park after Hurricane Camille (W. Swank, personal communication, 1991). Certain mountainous areas in the northeast have documented elevated turbidity levels in streams and reservoirs after storm events, possibly due to channel scour (Jim Porter, NYC DEP, pers. comm. 30 January 1998).

Mass movement erosion events would probably only effect MDC watersheds during infrequent events on limited sites. The limited areas where small slides and soil slumps do occur on MDC watersheds are associated with unstable slopes adjacent to reservoirs (with steep slopes, water level changes, and wave action causing instability), poorly vegetated, unstable slopes especially adjacent to streams, and limited steep sand and gravel slopes especially those with exposed soils due to recreation access, powerlines, or both (B. Spencer, pers. comm., 1991). Hewlett and Nutter (1969) also note that large, severe fires may contribute to mass movement through loosening surface soils and rocks.

Floods, fires, and heavy grazing do affect the ability of the forest to protect the watershed . Severe fires can reduce infiltration capacity through burning off of organic litter, sealing of soil surface pores, and creating a "non-wettable" highly erodible soil surface. For example, studies in Missouri and North Carolina of areas frequently burned showed infiltration capacity was greatly reduced; 2-8 times in Missouri and 25 times in North Carolina when compared to unburned areas (Dyrness 1965; Hewlett and Nutter 1969; Lull and Reinhart 1972). Fires are also linked with losses of both inorganic and organic particulates (Carlton 1990). Large severe fires can also contribute to high flood flows which can increase stream channel scour and sedimentation. Rapid revegetation of burned areas and maintenance of a forest cover are the best guards against erosion/sedimentation from these two sources. For example, a watershed in New York went from 74% open to 16% open areas over a 20 year period through regrowth of forest and peak flows were reduced by 41%. In Tennessee a watershed went from 66% forested to 100% forested and summer peak flows were reduced from 73-92% (Lull and Reinhart 1972).

The relationship between deforestation and flooding was a controversial topic around the turn of the century, when many experts of the day advocated creating the National Forest system with a prime purpose of reducing flood hazard. This argument is basically supported by comparing heavily forested river basins with heavily developed and agricultural basins (Hewlett and Nutter 1969). Patric (1974) studied the impact of the hurricane of 1938 upon river flows. He noted that the Connecticut and Merrimac Rivers, where more than 35% of the drainage basin lands were opened through tree blowdown, had increased flows of nearly 25% the first year. Increased flows were concentrated in the summer months. Patric and Gould (1976) studied three Massachusetts river basins over the past 100 years and concluded that river flows decreased as reforestation occurred. They also concluded that the flashiness of streams increased with urbanization.

Even in a forested watershed, storm flow contributes a significant amount of the annual sedimentation. For example Hewlett and Nutter (1969) state that it is not unusual for 75% of total annual suspended sediments to come from one or two storms. Bormann et al (1969) reported that one storm in a New Hampshire watershed was responsible for 64% of the particulate matter coming off the watershed for a two year period. Hewlett and Nutter (1969) note that:

> On small watersheds, experiments have shown that agricultural, urban development, and construction can increase the frequency and magnitude of peak rate of flow. Denudation and compaction of soil are often blamed as a prime factor in floods.

The authors conclude that past accelerated erosion was caused by unwise cultivation and excessive grazing. Heavy grazing by domestic animals does cause increased erosion; however, it rarely occurs in the forests of the northeast.

One of the key values of a forest is that of a storehouse for various elements and materials which would otherwise be lost into tributaries. An emerging value of forests is that of sinks for the deposition of atmospheric pollutants (including heavy metals and acids). Forest vegetation, tree trunks, and forest soils are all extremely valuable in holding or chemically ameliorating incoming pollutants. A key part of this value is the multi-storied vegetation of a forest and its ability to greatly slow the flow of water through the system, allowing additional time for buffering chemical reactions to occur. Carlton (1990) provides a detailed discussion of the values of a multi-layered forest.

In a Berkshire County forest study, Art and Dethier (1986) found that forests increased the pH from rain (4.2 pH) to streamflow (7.0 pH). Hemond and Eshleman (1984) suggested that uptake of nitrate by the growing forest helped increase the alkalinity of streams in the Ware River watershed.

Forests function as regulators of water yield. Not only do forests have value in regulating and minimizing particulates, suspended sediments, and dissolved solids (especially nutrients), they also regulate the overall amounts of these materials leaving the forest soils by reducing flows. For example, studies at Hubbard Brook, New Hampshire show that concentrations of particulates (fine, partially decomposed organic matter) are directly related to stream volume (Carlton 1990). This process is also the main way in which phosphorus, an element being watched carefully by MDC, exits forested watersheds.

C. REVIEW OF WATERSHED AND FOREST MANAGEMENT PLANS FOR NON-MDC AREAS

The purpose of this section is to briefly review the organization, contents, and ideas of other recent forest management plans so that applicable concepts can be utilized in this plan. The thirteen plans that were reviewed included federal, state, municipal, and non-profit conservation organizations, three of which were water supply agencies. Letters requesting plans were sent to twelve large water suppliers, without response. An effort will be made to obtain and review more examples of watershed forest management plans as they become available.

1. Plan Organization/Contents:

The process for developing comprehensive plans involves variations on the following steps:

a.) Establish goals and objectives, given legal mandates, organizational purposes, and public needs
b.) Inventory resources (usually including water, recreation, aesthetics, natural areas, wilderness, forest, timber, wildlife, fire, insects and diseases, etc.)
c). Study past activities
d). Develop recommendations and operating guidelines based on technical knowledge, public desires, and desired future conditions, usually including "zoning" of lands by type of management approach to be applied there, and some listing of alternatives considered
e.) Determine impact of recommendations on various resources
f.) Formulate balanced action plan
g.) Complete public review and revise plan
h.) Complete detailed implementation plan including budget for various

items
(Commonwealth of Pennsylvania 1985a-d; USDA Forest Service 1986; USDA Forest Service, n.d.; State of Vermont, n.d.; State of New Hampshire 1994; State of New Jersey 1984; Rivers 1981).

2. Goals/Objectives/Guidelines

Many of the reviewed plans contained goals, objectives and guidelines for management, with varying degrees of detail. The three water suppliers focused on water supply protection as their main goal. South Central Connecticut Regional Water Authority (1983) states:

> policies guiding the development of the Plan provide that water supply uses have priority in the event of any land use conflicts.

City of Tacoma, Washington (1987) states the purpose of the plan is to:

> develop a forest management plan for city-owned lands focusing on water quality protection, erosion control, wildlife habitat, fishery protection, riparian zone management, timber resource management, and potential revenue generation.

Other land holdings had varying goals for the plans ranging from integrated use or sustained yield management (on national and state forests) to inventorying, preserving, restoring, and enhancing ecological integrity and native biodiversity (Massachusetts Audubon Society, 1989).

"Objectives" were defined in some of the management plans. Objectives are useful in that they are more specific than goals, and are useful in detailing the goal in each area of interest. For example, Tiadaghton State Forest Management plan (1985a-d) listed its goal as sustainable yield which is compatible with other resources. Their objectives dealt with more specific areas such as fire, insect, disease, species diversity, economics, etc. Objectives also specify the priority of forest management at stand-level (for example, salvage cuttings or cutting in young or old or overstocked stands) once a general approach to forest management has been outlined in a goal.

The Nash Stream Forest Management Plan (State of New Hampshire 1994) utilized a "management vision" followed by management principles and goals, and contained detailed vision-goal-objective statements. For example, one of the *management visions* was to protect the natural qualities and integrity of the land and its resources. An associated *principle* stated that the location of management activities would be based on land and ecological capabilities. A correlary *goal* stated that uneven-aged management would be the silvicultural method of choice. A correlary *objective* indicated that the state should strive to achieve and maintain an ecologically sustainable multiple-use forest. Four strategies were outlined for implementing that objective.

Objectives often leave a wide range of options within a given area. Several of the plans relied heavily upon guidelines or Best Management Practices (BMP's) to describe how goals and objectives would be implemented or at least to specify limits to management activities where necessary. For example, Tiadaghton State Forest (Comm. of PA, 1985b) lists zones limiting cutting activities around trails, streams, lakes, ponds, and public roads. Guidelines are also used to delineate zones and describe the types of management planned for each zone. The USDA Forest Service (n.d.) lists eleven distinct zones in the Green Mountain National Forest ranging in management intensity from "wilderness" to "intensively managed mosaic." The Executive Office of Environmental Affairs in Massachusetts has adopted a zoning system for state lands which defines three broad zones.

3. Unique Attributes/Ideas

Although many of the reviewed plans were similar in approach, specific attributes and/or ideas may be useful in MDC's present planning efforts. For example:

- ▹ The length of the plans varied considerably. While longer plans were often more detailed and useful (the set of plans for the Tiadaghton State Forest in Pennsylvania was a good example), the State of New Jersey's plan for High Point State Park (1984) is an example of a very concise and well-constructed plan.

- ▹ Roxbury State Forest in Vermont included maps detailing the areas, timing, and descriptions of forest management activities for the next ten years. This plan also included the location and extent of forest road work planned for the next ten years, and a glossary of terms.

- ▹ The High Point State Park plan (State of New Jersey 1984) assembled zones into large blocks where possible, so that intensity of management was the same in each large block. The South Central Connecticut Regional Water Authority (1989) maintained at least 2,000 acres in a block of forest that would not be cut in the ten year period so that six wildlife species may benefit from the lack of disturbance in the uncut block. This plan also includes areas where vehicle access is limited to minimize disturbance to wildlife.

- The plan for Tiadaghton State Forest in Pennsylvania includes a section on genetic improvemen, outlining the goal of certain silvicultural activities to preserve genotypes compatible with sites, encourage species diversity, increase forest resistance to environmental stresses, and insure adequate survival of regeneration.

- The USDA Forest Service's White Mountain National Forest Plan (1986) includes a section outlining monitoring and evaluation steps during the planning period. The Forest Service uses a detailed process of public involvement which begins with "issue generation" and evaluation of alternatives generated through public involvement and inventory work. This plan also has a detailed list of standards and guidelines and a specific "to do" list for implementing the plan.

- Massachusetts Audubon Society's Wachusett Meadows Plan includes specific operating guidelines which define the "habitat standard" for a long list of habitats. The guidelines define recommended actions for each habitat on the property.

- The Nash Stream Forest Plan (State of New Hampshire 1994) covers a 40,000 acre, recently acquired parcel in northern New Hampshire, and has many similarities to the Quabbin Land Management Plan. The plan describes 15 "ecological land groups" or land/soil/forest associations upon which management is based. It includes several categories of ecologically sensitive land where low-intensity management will occur, and calls for uneven-aged management with strict protection of water resources during operations. Timber sales are coordinated by an interdisciplinary team. Guidelines for riparian forest management strive to ensure sustained tree recruitment and accumulation of large woody debris. The plan lists 15 species of "management concern" and outlines practices for enhancing habitat for these species. Also included in the plan is a chapter on "Economic Considerations" which describes the local benefits of management.

D. FOREST MANAGEMENT SYSTEMS AND WATERSHED MANAGEMENT

1. Silvicultural Systems and Their Value in Watershed Protection

In this section, various systems of forest management will be briefly explained. Next, the value of these silvicultural systems and successional stages with regard to watershed manage-ment and protection will be examined, given relevant research.

First, an overview of watershed management as presented at an international symposium on watershed management:

> ...some deleterious effects on water resources are avoidable, inasmuch as they stem from inadequate, indifferent, or uncomprehending timber management. Others are inevitable and result, not from the level of management practice, but from the very fact of ecosystem disturbance. Management can only mitigate such effects, while enhancing the desirable...Watershed management seeks to recognize, understand, evaluate, and manipulate these interactions in a purposive way, to meet specific needs in given situations. (Jeffrey 1968, as cited in Rothacher 1970).

There are several silvicultural purposes for harvesting trees in a watershed protection context, including: improving vigor/health of the remaining trees (thinnings), creating openings for regeneration (regeneration cuts), and salvaging declining, dead, or downed trees (thinnings and salvage operations). The discipline of silviculture, defined as the application of forest ecology principles in producing and tending forests (see Smith 1986 for expanded definitions), includes two basic systems which link the above operations:

- The *even-aged system* manages forests which are of similar age-classes and includes the clearcutting, shelterwood, and seed tree methods of regeneration.

- The *uneven-aged system* manages forests to include three or more distinct age classes and includes the single tree and group selection methods of regeneration.

Both even-aged and uneven-aged systems include the thinning of forests to improve health and vigor and to salvage trees likely to die before the next cutting cycle. The three key differences between even-aged and uneven-aged systems lie in the regeneration methods, the type of successional species which are encouraged, and the ways in which age-classes are balanced.

In the even-aged system, regeneration is encouraged over large areas under moderate to high light conditions. This system encourages early successional species such as pine, cherry, ash, and birch, but adjustments can be made to accommodate moderately shade-tolerant species. This system produces a variety of even-aged forest types and balances age-classes across a large forest area.

In the uneven-aged system, regeneration is encouraged in small openings through the creation of diffuse light conditions. This system best meets the environmental requirements of species that have intermediate or high shade-tolerance such as hemlock, sugar maple, and beech. This system produces a mixture of age-classes in close association to one another and generally balances age-classes within each acre of forest, by allocating percentages of the growing space to young, medium and old trees. The uneven-aged system creates multi-storied forests with well-developed overstory, mid-story and understory layers. The uneven-aged system generally requires careful inventory, to assure that each cutting improves the balance within the forest (Arbogast 1957). However, new approaches to uneven-aged systems have simplified the system's implementation (Leak and Gottsacker 1985).

While this discussion compares even-aged and uneven-aged management, it should be noted that these systems exist on a continuum. For example, Bradshaw (1992) notes that the key parameter to use in distinguishing between these two systems is the size of the opening created. Where the openings created by the two systems are similar in size, the differences in the systems are small. In general, uneven-aged management creates gaps which are small enough for surrounding trees to provide influence, protection or competition for new forest growth. A comparison of commercial and MDC uneven-aged management appears in Appendix III.

The "passive" or "naturally-managed" forest is also included in this discussion as a third system. This system assumes that with minimal management a natural forest equilibrium will become established. Management may include fire suppression and limited vegetation manipulation geared at correcting some results of past human land use practices. Given the current condition of the Quabbin forest, the naturally-managed system is most affected by periodic natural disturbances (e.g. wind, fire, insects and diseases). The even-aged and uneven-aged management systems are also affected by periodic natural disturbance, but such management tends to lessen the overall impact of such disturbance. Overlain upon each of the three management systems is the increasing impact of air pollution, which will be discussed in more detail in section F. below.

The differences between the three basic systems (even-aged, uneven-aged, and naturally-managed forests) include:

a.) the amount, height, age, species composition, and diversity of forest cover on a given site at a given time,

b.) the frequency and the impact of, as well as the response to, management activities, natural disturbances, and environmental pollution, and c.) the hydrologic response of watersheds under these systems.

In designing the forest management approach described in the Quabbin Land Management Plan, the MDC has considered the basic strengths and weaknesses of each system with regard to watershed protection. Specific impacts from various types of forest cutting will be examined in section E. below. The following discussion will focus on the watershed protection values of various successional and structural forest components including forests undisturbed by direct human land use or management.

Nutrient Releases:

The impact of nutrients in the MDC tributaries and reservoirs is of concern to MDC staff. For example, in 1989, MDC, in conjunction with the Department of Environmental Protection, Division of Water Pollution Control, conducted an intensive analysis of tributary water quality at Quabbin and Ware River. The report emphasizes nutrients and metals, for which data had been lacking in the past (Commonwealth of Massachusetts 1990). Several nutrients, such as nitrates, are specifically regulated by the U.S. Safe Drinking Water Act regulations. Studies also show that increased releases of nitrates will decrease pH and reduce alkalinity in streams (Likens 1970; Vitousek 1977; Vitousek et al. 1982). Many nutrients, such as phosphorus and nitrates, also affect the growth of algae in reservoirs, an important concern of the Division.

Several researchers have noted differences in nutrient releases coming from forests of different ages and types, and following different types of disturbances. Nutrient cycling is affected by climate, soils/geology, and vegetation (Vitousek 1977; Vitousek and Melillo 1979; Leak and Martin 1975; Art and Dethier 1986; Vitousek et al. 1982; Robinson et al. 1979; Timmons et al. 1977; Marks and Bormann 1972; Bormann et al. 1969; Rice and Pancholy 1972, 1973, 1974).

The original theory regarding nutrient release of various successional stages and ages of forests was put forth by Eugene Odum (Odum 1969). He suggested that ecosystems become better conservators of nutrients as they mature. At a certain point in the life cycle of an ecosystem, respiration would equal production (e.g. net production equals zero). At this point a steady state would be reached, where input of nutrients would equal exit of nutrients.

Vitousek and Reiners (1975) conducted experiments to test Odum's theory. They studied four watersheds on Mt. Moosilake in New Hampshire, focusing on nitrogen, since:

a.) nitrogen is frequently a limiting element in ecosystems, b.) the process of nitrification (process by which the less mobile ammonium ion is chemically changed to the more mobile nitrate ion) is key in the loss of cations, and

c.) nitrogen is sensitive to disturbance/recovery phenomena in this region.

The authors found that nitrate export into streams was seven times higher in the mature ecosystem which had been undisturbed by logging. From their calculations, they determined that input of nitrogen and exit of nitrogen from this watershed was approximately equal. The key difference between the mature versus successional watersheds was that while the nitrate flow was relatively constant year round for the mature watershed, the successional watersheds showed a pronounced decline in nitrate release during the growing season. Thus, watersheds in successional stages before maturity retained nitrogen more efficiently. Potassium, magnesium, and calcium were also retained more efficiently by the earlier successional stages. Van Miegroet and Johnson (1993) also reported that nitrate leaching losses were larger in mature versus young, vigorously growing forests.

Vitousek and Reiners (1975) noted a study of a 450 year old Douglas fir forest in the Pacific Northwest which had a low loss of nitrate because it was still accumulating biomass. The authors hypothesize that this may be the case where long-lived species grow in areas which lack recurrent large-scale disturbance, while in areas with large-scale cyclic patterns of growth and destruction, the process of biomass accumulation is rarely in a steady state. Where a system is dominated by single tree death (as on the site of Mt. Moosilake and in the Pacific Northwest), a steady state is reached and nutrient conservation declines. Overall, the authors state that intermediate-aged successional ecosystems will have lower nutrient losses than either very young or very old ecosystems, as they are accumulating nutrients at the greatest rate. Similar conclusions regarding nutrient export and successional stage were reached by Tate and Meyer (1983) for dissolved organic carbon export, and by Johnson and Swank (1973) for Na^+, K^+, Ca^{++} and Mg^{++}.

Marks and Bormann (1972) conclude that:

> It is not unreasonable to suggest that old overmature stands that are not increasing rapidly in vegetative mass or humus depth become less effective in utilizing available nutrients, resulting in an increased nutrient discharge into the streamwater...The results of this study seem to show a good relationship between streamwater NO_{3-} during spring-summer period and stand age or age since disturbance.

A study by Leak and Martin (1975) compared six watersheds in New Hampshire and found 10.3 parts per million (ppm) of nitrate after clear cutting, trace amounts in mid-aged forests (.15-.8 for stands 75-125 years of age), and 4.8 ppm in an old-aged forest (the U.S. drinking water standard for nitrate is 10 ppm). The authors concluded that a correlation existed between stand age and nitrate discharge.

One of the "old growth" watersheds studied was The Bowl in the White Mountains. This small watershed has been protected from past disturbances and contains trees up to 240 years of age; average age is ~200 years. An earlier study of The Bowl found nitrate concentrations taken in June-August higher than those found in younger watersheds at the nearby Hubbard Brook Experimental Forest (Leak 1973). Nitrates in The Bowl were higher than in younger stands due to the increasing biomass in vegetation and humus in those stands. Martin (1979) also studied The Bowl and found higher nitrate concentrations there, especially during the growing season.

Pickett and White (1985) concluded that net nutrient demand by living biomass is lower in older forests, so it is possible that nutrient availability could increase with age, even without the canopy turnover associated with large disturbances. This process evaluation is in accord with the variability found in nutrient releases from recently disturbed, middle-aged, and old forests in New Hampshire (Martin 1979). Robinson et al (1979), in their study of nitrates in small streams, concluded that vigorous forests tend to reduce nitrates during the growing season. Waring and Schlesinger (1985) conclude that a growing forest will retain the annual input of limiting nutrients, but that the long-term retention of essential nutrients is lower when forest biomass is not accumulating. Pickett and White (1985) note the need for increased study of nutrient losses in undisturbed, old forests.

Vitousek (1977) studied fourteen watersheds in New Hampshire and concluded that older-aged watersheds had high relatively constant nitrates, while successional forests had lower growing season nitrates. In this study, old-aged watersheds averaging 6.62 times the nitrate releases of younger watersheds. Part of this study involved trenching around plots, and the conclusion from these plot studies was that when plant uptake was prevented, higher losses of those nutrients important to plants occurred.

While Vitousek felt his theory held true for nitrogen and potassium (elements stored in large amounts in forests), it did not hold true for sodium, sulphur, calcium, and magnesium (elements stored in small amounts in forests). The situation with phosphorus, iron, and aluminum is more complex. His studies showed that early-mid successional stages were the most effective in nitrate control as biomass accumulation was largest. In summary, he felt that "steady state" (old-aged) watershed ecosystems use lower amounts of essential plant nutrients than rapidly growing intermediate-aged successional ecosystems.

With regard to the importance of vegetation (as opposed to soils/geology and climate) in determining streamwater chemistry Vitousek writes:

> An understanding of the successional position of vegetation is essential to a proper interpretation of streamwater chemistry or element budgets in small watershed studies.

Rice and Pancholy (1972, 1973, 1974) studied the nitrification process in various stages of succession in oak-pine forests of Oklahoma. These studies analyzed soils, not streamwater as in the studies described above. Results indicate that the ability to inhibit the conversion from ammonium nitrogen to the more mobile nitrate nitrogen (the process of nitrification) increases with successional stages, from field to the climax association forest. The authors suggested that tannins produced by the forest may help in inhibiting nitrification. However, Vitousek (1977) felt that the key to explaining element loss is in examining changes in biomass storage, not changes in inhibition of nitrification. Vitousek and Melillo (1979) list eight processes by which nitrogen is kept in a system, including prevention of nitrification.

Vitousek and Melillo (1979) noted correlations with increased nitrates after large disturbances at Hubbard Brook, NH and Coweeta, NC. The authors define destructive disturbance as any disturbance, natural or human-caused, which destroys the dominant vegetation or its ability to take up nutrients. At Coweeta, the most recently disturbed forests had the highest nitrate losses, with elevated losses still measured twenty years after the disturbance. The authors theorize that after a large disturbance, decomposition and nutrient mineralization increase resulting in increased elemental losses. In addition, in the first years after disturbance, higher streamflows will further increase elemental loss. They felt that hardwood litter would be more susceptible to this process as nitrogen mineralization is higher in deciduous versus coniferous forests. Vitousek et al. 1982 conclude that low nitrogen availability before disturbance is key to nitrogen loss after disturbance - more so than nitrification inhibition.

Pickett and White (1985) note that windstorms have a somewhat smaller impact on nutrient availability than clear cutting, due to the debris left on the ground. However, with the increased fire risk associated with blowdown, the increases of nitrogen and phosphorus which occur immediately after severe fires due to increased soil temperature and soil moisture should also be considered. For example, nitrates increased by up to nine times and phosphorus by more than three times after extensive windthrow followed the next year by a wildfire in a monitored watershed in Ontario (Schindler et al, 1980). Van Miegroet and Johnson (1993) report that periodic outbreaks of defoliating insects have increased nitrification resulting in elevated soil and streamwater nitrate levels at Hubbard Brook and Coweeta experimental watersheds. Picket and White (1985) also note that nitrate leaching has been associated with disturbances from diseases affecting forests, and conclude that nitrogen availability appears to be increased by disturbance.

The speed with which regrowth occurs can affect nitrogen losses. For example, pioneer species such as aspen and pin cherry begin uptake of nutrients quickly after disturbance (Bormann et al. 1969). Bormann et al (1974) noted that even fast-growing pin cherry regeneration may take up to four years after a disturbance before nutrient losses are effectively controlled. Young, dense, early successional forests with closed canopies rapidly begin the process of recovery. Van Miegroet and Johnson (1993) state that stand age is important in determining nitrogen uptake,with accumulation rates reaching a maximum when canopy closure occurs. Waring and Schlesinger (1985) report that leaf area index also peaks just before canopy closure, nd that a 10 year old Scots pine stand in Sweden had 50% higher leaf area index than a 150 year old forest. Marks and Bormann (1972) found that a 4-6 year old stand of pin cherry may take up 50% more nitrogen than a mature forest. The authors conclude:

> The extent of nutrient loss from a forest ecosystem should nevertheless decrease according to the rate of revegetation. Dense stands of fast-growing, early successional species will exhibit pronounced regulation of ecosystem function soon after the disturbance.

Buzzell (1991) examined forests at Wachusett Reservoir which were blown down by a windstorm. He noted that tree seedlings were more dense in affected areas which had been silviculturally managed in the past. For example, seedlings above one foot in height but less than one inch in diameter were more than twice as dense in areas previously managed. Kyker-Snowman (1989a) found similar conditions when comparing regeneration plots in managed and unmanaged forests at Quabbin Reservoir, both of which had low deer populations due to hunting. In these plots, seedlings above one foot in height but less than one inch in diameter were more than four times as dense in managed forest plots.

Other Water Quality Parameters:

In addition to the fate of nutrients, the Division of Watershed Management is concerned about many other water quality parameters, including: turbidity, total dissolved solids, pH, alkalinity, metals, organics, bacteria (total and fecal coliform), viruses, and protozoa (e.g. Giardia and Cryptosporidium). While bacteria is the parameter most closely watched by the Division and regulatory agencies, it is monitored chiefly in regard to human and animal pollution. Turbidity, a measure of the optical cloudiness of water, has been a parameter in many watershed studies. Turbidity is easily measured, has a U.S. drinking water standard, and is an indicator of the overall water quality. Turbidity is also sensitive to the impacts of various land use activities and is a good parameter in assessing non-point source pollution. Waters with high turbidity make chlorination less effective, especially with regard to Giardia/Cryptosporidium. This is the principle reason for the recent change of the U.S. drinking water turbidity standard from 5 NTU (Nephalometric Turbidity Units) to 1 NTU.

Like turbidity, pH is a good general indicator of the condition of a watershed and has also been studied widely. Total dissolved or suspended solids and sediments are good indicators of overall watershed condition, but are measured less frequently in studies than turbidity; interestingly, many studies fail to find a simple conversion from turbidity to sedimentation. The remaining parameters - metals, organics, protozoa, and viruses - are difficult to measure and are generally associated with either urban or agricultural runoff or human and animal pollution. The exception is the case of increased metals leaching with increased soil water acidity.

This section will chiefly examine the variations of turbidity, pH and alkalinity, and sediment measures (total dissolved and suspended solids, and total sediment) with regard to forests of different ages and types, and following different types of disturbances. Examination of the impacts of specific forestry operations will occur in section E. below.

The most dramatic study of changes in export of particulate matter from a watershed was at Hubbard Brook, NH, where a small watershed was cleared and the downed trees left in place. After clearing, herbicides were applied to prevent regrowth for three seasons (Bormann et al. 1974). In this experiment, export of particulate matter increased from 2.5 metric tons/km^2/year to 38 metric tons/km^2/year. Interestingly, the export of particulates showed only minor changes the first two years after clearing and a sharp increase the third year. Although streamwater flows increased significantly in this study (41%,28%, and 26% respectively the first three years), the authors felt that increased particulates related to the increased erodibility of the watershed after deforestation, not increased streamwater flows. They concluded that streamwater particulates were significantly regulated by biotic conditions.

Exports of particulate matter occur in watersheds chiefly during brief periods of high runoff. For example, Bormann et al. (1974) showed that significantly higher particulates left two watersheds under study (one with a mature second-growth hardwood forest cover and one deforested as described above) during periods of higher streamflows. In the watershed covered by a mature forest, 78% of particulates were removed by flows greater than 2 cubic feet per second. These flows occurred only .4% of the period studied and accounted for only 9% of water yields. In another study, 64% of the particulates exported from a forested watershed during a two year period occurred during one storm (Bormann et al. 1969). The authors concluded that the reaction of a watershed during larger storms will dictate the overall yield of particulates. They further concluded that summer storms are more effective in removing particulates than are winter storms. For example, the watershed with mature forest cover had a 30% greater erodibility during summer months, due to increased biotic activity and turnover and increased erodibility of convection rain events.

Particulates in the watershed with mature cover originated within the stream channel (rotting fallen leaves, etc.). Particulates from the deforested watershed originated from outside the stream channels (minor channels and surface flow). In general, the authors noted that the increased erodibility in the deforested watershed was due to the decreased biotic protection occurring there. The biotic protection afforded by a forest includes:

a.) a modest excess of primary productivity over decomposition,

b.) close biotic regulation of water chemistry and erodibility,

c.) biotic control over the hydrologic cycle, as flow and sediment load are exponentially related (Bormann et al. 1969), and

d.) allelopathic control over soil microorganisms by the forest biota.

Forest regulation of erodibility includes the following factors:

a.) conversion of surface to subsurface flow,

b.) increased retention and detention storage due to organic matter,

c.) protection of mineral soil from rain by litter,

d.) binding effects of roots,

e.) beneficial effects of debris dams, and

f.) presence of hardwood leaves on stream banks (Bormann et al. 1974).

The authors note that, unless there is severe and widespread destruction of the forest floor, erodibility following disturbance will remain low long enough for early successional species to take hold. Bormann et al. (1969) note that increases in biomass and organic debris are inversely related to the frequency of high discharge events and the erodibility of a watershed. The authors summarize:

> Severe reductions in biomass resulting from clear-cutting, windstorms, or fire would negate the above [biotic protection] effects, while sharp increases in biomass associated with secondary succession would enhance them.

In addition to affecting the vegetation cover, one of the key impacts of catastrophic hurricanes may be the soil disturbance associated with the uprooting of trees. Stephens (1956) intensively studied one acre of the Harvard Forest in Petersham and concluded that uprooting was an important influence on the life history of that forest. He recorded four major uprooting occurrences in the past 500 years, impacting 707 to 1802 square feet within the acre of forest. Of the 62 mounds and pits found on the acre, 59 were attributed to uprooting from hurricanes.

The overall beneficial effect of forest cover on acidity was noted in section B. above. A study in the Berkshires in Massachusetts recorded a change from pH 4.2 (rain) to 7.0 (streamflow) in a forested system (Art and Dethier 1986). The authors found that species composition played a more important role than forest age with regard to pH. However, the soil pH in the "O horizon" (soil layer nearest the surface) was correlated with the age of the forest, with forests over 140 years of age averaging O horizon pH of 3.92 and those less than 140 years averaging 4.21 pH. The authors cite three studies (Robertson and Vitousek 1981, Throne and Hamburg 1985, and Krug and Frink 1983; all as cited in Art and Dethier 1986) which indicate that acidification increases with successional sequences following agricultural abandonment.

Influences which increase nitrates in the water (see nutrient discussion above) also reduce stream alkalinity. Art and Dethier (1986) noted that pH changes are very flow path related; subsurface horizontal flow is biota regulated, while subsurface vertical flow through mineral soil is regulated by geologic makeup. The authors also noted that levels of water-extractable aluminum correlated with lowered soil pH. They observed that aluminum reached streams only when a direct hydrologic connection forms between soil organic layers and surface water; water percolating through mineral soil tends to have a higher pH and lower aluminum. Bormann et al. (1974) found decreased pH and significantly increased aluminum, iron, and magnesium in a deforested watershed.

2. New England's Original Forests

a. Descriptions of the Original Forest

In the context of this section, New England's "original forest" is defined as the forest condition existing around the time of the first arrival of European settlers. There is much interest on the part of those managing and visiting Quabbin in knowing what the original forest in the region was like. Beyond this interest, studying the original forests and their stability - or instabililty - over the centuries will help to improve our understanding of the future which the current Quabbin forest may face. Examining how these forests have changed with the impacts of European settlement will also assist in future management decisions. This section will review the few analytical studies and the anecdotal and historical records that are available which help describe the original New England forest. Since very few forests remain which have not been significantly impacted by human activities or recent severe, natural disturbance, most of the literature reviewed is based on:

- studies of the few undisturbed forest sites,
- historical records or studies documenting the condition of New England forests since European settlement, or
- studies which trace present forests back to their condition before European settlement through careful site analysis.

For the pre-European settlement period, few historical records exist and analysis of present sites is difficult for that time period, except through pollen analysis which is limited to describing the basic species make-up. For example, Foster and Zebryk (1993) examined the 10,000 year pollen records for two lowland sites within the Quabbin watershed. At one site, hemlock was the dominant species for the past 8,000 years, decreasing after disturbance and recovering well after the disturbance.

One of the best detailed descriptions of a large tract of "original forest" is presented by Nichols (1913) in describing the Colebrook tract in northwestern Connecticut. This forest had not been cut and due to its location had not been burned or toppled by hurricane in over 300 years. Nichols felt it represented the condition of the "climax" forest in that region. This forest was dominated by hemlock and beech (comprising 55% of the stand) with sugar maple (12%), black birch (10%), red oak (6%) and chestnut (6%). Nichols noted the impressive size of the mature trees which averaged 250 years of age and the fact that the composition of the understory trees matched that of the overstory.

However, most of the few remaining tracts of original forest (which had not been impacted by human or natural disturbance) were blown down by the hurricane of 1938. Cline and Spurr (1942) is perhaps the best study of the remaining original forest prior to the hurricane of 1938. They studied 68 1/10 acre plots of remnant old growth stands and 23 plots in recently cut over remnant forests. They found that natural disturbance had markedly affected the composition of 80% of the plots. They felt that fire had a large impact on the history of the plots and that windthrow was the most common cause of death for large old trees. They also found that wind and fire impacts were invariably interconnected; wind damage contributing to later fires, and fires weakening trees and increasing susceptibility to future blowdown. They concluded that the majority of the primeval forest was in a state of flux where large trees were common but few areas were composed of stagnant stands of immense trees. They also concluded that eastern hemlock was the most abundant and aggressive species in the climax forest.

Foster (1988) utilized several methods to further analyze the old-growth forest in southern New Hampshire studied by Cline and Spurr. He concluded that the forest had a natural disturbance regime of frequent small and occasional broad-scale events. The large disturbances (hurricanes and fires) were historically important for stand initiation, opening large gaps and causing an even-aged forest to develop after the disturbance. He concluded, "there is no evidence that the last 350 years have provided the stability or growth patterns expected in a steady-state forest."

Leak (1973) studied "The Bowl," a 510-acre forest in New Hampshire which is one of the few remaining large tracts devoid of both human disturbance and major natural disturbances. He noted that this forest has limited species composition (chiefly yellow birch, red spruce, and balsam fir), fairly large sizes of key species, a full understory, and a well-developed diameter distribution. In the understory in the 0-9 millimeter diameter class, there were approximately 25,000 stems per acre, and approximately 2,000 stems per acre in the 10-99 millimeter diameter class.

However, an important question is: are remnants such as the Colebrook tract and "The Bowl" forest representative of most of the region's original forests? Braun (1950) hypothesized that much of New England was covered by an uninterrupted forest when the Pilgrims arrived except where fire or windfall temporarily destroyed the forest or where Native Americans had burned the forest. The following is her overall evaluation of the condition of the "primeval forest:"

> The primeval forests, then did not consist of stagnant stands of immense trees stretching with little change in composition over vast areas. Large trees were common, it is true, and limited areas did support climax stands, but the majority of stands undoubtedly were in a state of flux resulting from the dynamic action of wind, fire and other forces of nature. The various successional stages thus brought about, coupled with the effects of elevation, aspect and other factors of site, made the virgin forest highly variable in composition, density, and form.

A few studies have analyzed present-day forests in order to "reconstruct" their past. While this information is more detailed than historical records, it describes only very small sections of forests. For example, Oliver and Stephens (1977) analyzed the history of a one-acre plot within the Harvard Forest in Petersham. They noted the evidence of two hurricanes and a severe fire prior to 1800. They concluded that disturbances (allogenic influences) were more important than successional processes (autogenic influences) in forming the forest composition. They noted that the forest under study was composed of a mosaic of gaps due to past disturbances. The new forests generated after disturbances were generally of larger groupings which are associated with larger scale disturbances.

Henry and Swan (1974) reconstructed the 300-year history of a 1/10 acre uncut forest plot in southwest New Hampshire. They also concluded that successional processes did not contribute significantly to the composition of the forest and that disturbances were the chief influence. The plot was severely damaged twice in the 300-year period, once by a fire (1665) and once by hurricane (1938). The reconstructed forest of 1665 was also determined to be regenerated from an earlier major disturbance, possibly a hurricane which passed over the plot in 1635 (and which may have generated fuel for the 1665 fire). Recurring smaller disturbances also had significant impacts on the plot. Three windstorms which occurred between 1897-1921 destroyed nearly one-half of the canopy trees prior to the 1938 hurricane. In 1907 after no large-scale disturbance since 1665, the plot contained only three trees 25-30 inches in diameter and none larger than 30 inches. Interestingly, eastern hemlock was the only tree species which was consistently present over the 300-year study period, due to its adaptability.

b. Natural Disturbance in the Original Forest

White (1979) notes that the death of trees results from an accumulation of exogenously caused injuries and diseases rather than from senescence. Stephens (1956) documented four hurricanes in the past 500 years which caused significant uprooting of trees on the one-acre plot studied at Harvard Forest in Petersham. White notes that impacts from individual disturbances are often interactive with windstorms, weakening surviving trees to disease and increasing the chances of severe fires. He notes that researchers increasingly feel that disturbances (allogenesis) play a more important role in forest structure than progressive succession (autogenesis), and consequently that the concept of "climax" is being revisited. Stevens (1990) notes that many ecologist are forsaking the "balance of nature theory" for a new theory in which nature is in a constant state of disturbance and fluctuation. He notes that, due to external disturbances, the "climax forest" is a transient condition at best, even in the absence of human disturbance. Raup (1957) notes:

> The ideas of community structure and the expression of dominance, that of biological succession, and finally, that of climax, are based largely upon the assumption of long term stability in the physical habitat... I see the

> community, not as a product of long term, slow development in a relatively stable physical habitat, but rather as the product of repeated major disturbances by factors largely external to vegetation. I must think of such disturbances, not as unusual departures from the normal, but as the normal itself.

Bormann and Likens (1979a) note:

> A growing body of literature has emphasized the importance of fire and wind as common, widespread perturbances that historically have shaped the structure and function of North American Forests...Several researchers, while recognizing the role of endogenous disturbance, have suggested that the development of forest ecosystems rarely achieves a steady state, but is interrupted by catastrophic exogenous disturbances at irregular and relatively short intervals...in central New England evidence suggests that strong cyclonic winds regularly interrupt autogenic development.

White (1979) notes:

> The idea of climax as stable equilibrium is hard to apply except in shady, mesic, disturbance-protected vegetation...Frequency, regularity, and magnitude of disturbance depends on topography, substrate, and state of vegetational cover. Landscapes contain a continuum from disturbance-prone situations to particularly protected ones. Both conditions serve as refugia for the other (re: seed sources, etc.).

Foster and Boose (1992) found three key factors affecting damage by hurricanes in central New England: exposure (slope orientation and angle), vegetation structure (height and age), and vegetation composition (forest types). They constructed a simple model which estimates the impact of a major hurricane on forests in the central New England region. The model includes three exposure classes:

- exposed (level sites or slopes oriented in a windward direction, i.e. E, SE),
- intermediate (5-10% slope and W, NW, or N exposure),
- protected (moderate-steep slopes in the lee of the prevailing wind - W, NW, and N exposure).

For Harvard Forest acreage, land fell into the following class breakdown: protected - 10%, intermediate - 40% and exposed - 50%. The study of the impact of the 1938 hurricane upon the Harvard Forest showed that forests greater than 80 feet in height sustained windthrow of 75% of the trees or more in most stands. Percent damage was linearly related to tree height. In general, management which encourages hardwoods over conifers, and younger, shorter forests, will reduce the overall risk to hurricane damage.

In examining the effects of exogenous versus endogenous processes upon a forest, the specific site conditions should be examined in order to determine the susceptibility of the site to exogenous disturbances.

c. Changes in the Original Forests Since European Settlement

Harvard Forest, on the Quabbin watershed, has been the site of extensive studies during the past several decades on this topic. For example, Foster (1992a) traced the land use history of a 1000-acre tract on Prospect Hill within the Harvard Forest. Of the original 25 ownership lots into which this tract was divided, the average lot was sold 13 times during the period of 1730-1910. The uses of this tract included: woodlot (13%), tilled fields (16%), pasture (70%), and marsh (1%). The generalized logging history included: clearing (1730-90), woodlot use (1790-1850), and pine harvesting (1850-1920). On a regional basis, Worcester County went from widespread forest at the time of settlement to 25% forested in 1880 and 75% forested in 1900. Human impacts, combined with periodic natural disturbance, have kept the forests of the Quabbin region in a continual state of flux for the past 250 years (Whitney 1991) and make the present forest quite different from the pre-settlement forest (Foster 1992b).

Foster et al. (1992) describe the modern Harvard Forest as unlike any preceding vegetation and a poor analogue for the pre-settlement forest, although it may appear mature and stable. Many species which were common in pre-settlement forests are rare today. The authors state:

> The conclusion is that it is inevitable that ecologists will simplify greatly the history of inferred human impacts on the forest. However, a consideration of the extensive and variable nature of human use of the landscape suggests that we bear in mind some understanding of this complexity.

In trying to isolate the influence of past human disturbance versus those of the site, a study by Whitney (1991) will be useful to Quabbin managers. He measured 450 plots across the north Quabbin region and concluded that groundcover and shrubs are more associated with site and are a better indicator of site conditions in areas with past human disturbance. He found that past human disturbances can alter overstory tree composition for long time periods.

E. FOREST MANAGEMENT SYSTEMS AND WATER

1. Naturally-managed Forests

a. Water Yields

The water yields from naturally-managed forests are heavily influenced by tree growth and naturally-occurring forest disturbances (fires, wind, disease, and insects). Eschner and Satterlund (1965) studied a 491 square-mile watershed in the Adirondack Mountains of New York from 1912-1962. This study is particularly relevant to an examination of the impact of naturally-managed forests upon water yields. The land use on the watershed up to 1910 included land clearings, extensive fires, and heavy forest cuttings (chiefly logging of softwoods) which involved almost all of the watershed. In the late 1800's, the state of New York began purchasing lands in the watershed for the Adirondack Forest Preserve. From 1890 to 1910 the percentage of state-owned Forest Preserve in the watershed increased from 16% to 73%. The management policies of the Forest Preserve included laws against any cutting of trees and an active program of forest fire suppression.

The average forest density (in basal area) of the watershed increased from 65 square feet per acre in 1912 to 107 square feet per acre in 1952, due to forest growth and restrictions on cutting. Average basal area decreased to 97 square feet per acre in 1963 due in part to mortality from a windstorm in 1950. Another impact upon the watershed was a large increase in the beaver population during the study period. Throughout the Adirondacks, the number of beaver increased from an estimated 10 individuals in 1895 to an estimated 20,000 individuals by 1914, due to a prohibition on trapping introduced in 1895 and the introduction of 25 Canadian beaver and 14 Yellowstone Park beaver between 1901 and 1907. In 1965, nearly every perennial drainage in the watershed had resident beaver.

The combined effects of unregulated forest growth and the increased number of beaver dams reduced the annual water yield of the watershed significantly; by 7.72 area-inches or 23% from 1912 to 1950. The authors postulated that forest growth reduced water yields through changes in evapotranspiration and snowmelt and beaver reduced yields through losses due to evaporation from beaver ponds. Although the net effect from beaver was a reduction in water yield, they tended to increase dormant season flow and decrease runoff time due to the reduced interception of trees killed in flooded areas. Conversely, increased forest growth tended to lengthen runoff time. The effect of unregulated forest growth in lowering water yields was offset by increased in water yields resulting from the paving, straightening, and widening of 75 miles of roads within the watershed during the study period.

The trend of decreased water yields from 1912-1950 was reversed due to the large number of trees that were killed by the storm and the continued increase in mortality during the 13 years after the storm. The authors summarized the impact of the 1950 windstorm:

> The storm of November, 1950, disrupted the associated patterns of forest stand development and streamflow change, returning both to a point nearer their 1912 levels.

In another study, Eschner (1978) analyzed four small watersheds in the Adirondack Mountains of New York. One watershed, the East Branch of the Ausable River, was heavily impacted by logging, farming, and fires up to the early 1900's. Of the four watersheds, only the East Branch of the Ausable River was unaffected by the windstorm of 1950. Thus, this watershed offers a good example of a 42 year, stream-gauged period of uninterrupted forest re-growth. During this period, streamflow decreased by 4.2 area inches. Eschner concluded that this decrease was probably due to the natural regrowth of vegetation.

b. Water Quality

There have been few long-term studies of the impact of naturally-managed forests upon water quality. Several studies were cited above with regard to the impacts of old forests upon nutrient releases and the processes which are apparently involved. Other areas where naturally-managed forests may differ from actively-managed forests include response to natural disturbances, and nutrient/sediment interactions in stream channels.

The impact of disturbance is perhaps the key difference between a naturally-managed and actively-managed forest. In the actively-managed forest, silvicultural management is in effect a deliberate and regulated form of disturbance. In the naturally-managed forest, most disturbance is the result of unregulated natural events (e.g. wind, fire, disease, insects, ice). While both actively-managed and naturally-managed forests will be exposed to certain recurring natural disturbances (e.g. hurricanes), the two systems may respond to these disturbances very differently.

In recent years, even forests isolated from developed areas are being increasingly impacted by human factors (air pollution, introduced insect/disease complexes, wildlife browsing). Eschner and Mader (1975) note:

> When extensive areas of relatively stable vegetation are set aside for wilderness, man's activities are sharply restricted. However, changes in the vegetation continue, and in some cases the possibility of catastrophic change

> increases...Treatment of large areas of watershed as wilderness, currently advocated by several interest groups, may not be consonant with management for maximum yields or protection of areas. On land long-undisturbed, use of water by vegetation may be maximized and water yield reduced, while hazards of windthrow, insect, disease, or fire damage may increase.

Hewlett and Nutter (1969), in defining pollution, mention the potential impact of natural disturbances upon water quality:

> Because natural waters already carry materials which can degrade water for certain uses, we have some difficulty specifying just what 'pollution' is. Natural water quality over the centuries has evolved the stream ecosystem under conditions which we might, rather pointlessly, refer to as 'natural pollution.' For our purposes, however, we shall regard pollution as man-caused and think of polluted waters as those degraded below the natural level by some activity of man. In this sense, therefore, unabused forests and wildlands do not produce polluted waters, although they may at times produce water of impaired quality.

Parsons et al. (1994) in a study of the impact of gap size on extractable soil nitrate stated:

> Large-scale mortality events leading to macroscale gap formation, which involves the simultaneous death of many adjacent trees over thousands or tens of thousands of square meters, are known to increase mineralization and nitrification rates in temperate forest ecosystems.

Tamm (1991), in reviewing the role of nitrogen in terrestrial ecosystems, noted:

> Natural agents such as storms, insect defoliations, and, above all, fire may destroy the existing vegetation and stimulate both nitrogen mineralization and nitrification, leading to temporary losses of nitrate.

Corbett and Spencer (1975) report that Hurricane Agnes and the 14 inches of rain that accompanied it caused significant erosional impacts to the Baltimore Municipal Watershed, chiefly due to streambank cutting and channel slumping. The authors note that these types of impacts are more related to channel depth than condition of forest cover. Hurricane Hugo caused extensive damage to coastal South Carolina. The U.S.D.A. Southeast Forest Experiment Station monitored stream waters within the Frances Marion National Forest before and after the hurricane, with a gap in monitoring for several months after the hurricane, due to access problems (McKee 1993, pers. comm.). The forest before the storm was mature pine-hardwoods and much of it was windthrown or snapped by the storm. Preliminary results show increased nitrogen in streams compared with levels found in regular monitoring done before the storm (Swank, Harms, Neary, Benston, McKee, and Hanson 1990, 1991, pers. comm.).

Researchers in South Carolina are also concerned about the threat of a large forest fire due to the amount of downed material which has increased from 8 tons/acre before the storm to 100 tons/acre after the storm. After a 1.6 acre simulated hurricane "pulldown" at the Harvard Forest,Carlson (1994) reported that downed woody debris increased from 4.1 tons/hectare in a control area to 33.5 tons/hectare. He suggests that the potential threat of fire will increase in the next several years as pulled-over trees die.

Numerous studies show that impacts from forest blowdown or a combination of blowdown and forest fire can increase tributary nitrate and phosphorus exports by several times background levels (Verry 1986 and Packer 1967 as cited in Ottenheimer 1992; McColl and Grigal 1975: Wright 1976; Schindler et al. 1979). Soil disturbance from blowdown of large numbers of trees may also result in significant erosion (Patric 1984; White et al. 1980 and Swanson 1982, all cited in Ottenheimer, 1992). Water quality after extensive windthrow and fire confirm that dissolved nutrients and in some cases, sediment, acidity, and total organic carbon can be elevated for several years (Patric 1984 and Swanson 1982 as cited in Ottenheimer 1992; Verry 1986; Schindler et al. 1980; Wright 1976; Corbett and Spencer 1975; McColl and Grigal 1975; Dobson et al. 1990; Dyrness 1965 and McKee 1993 pers. comm.). For example, nitrates increased by up to nine times and phosphorus by more than three times after extensive windthrow followed the next year by a wildfire in a monitored watershed in Ontario (Schindler et al. 1980).

Dobson et al. (1990), in reviewing data from hundreds of lakes in New York, New Hampshire and Sweden, found strong spatial and temporal associations between percentage of watersheds affected by large blowdown events and long-term lowered pH in basin lakes. They concluded that extensive blowdown alters hydrologic pathways by channeling flow through "pipes" created by rotting roots so that water is less buffered by subsurface soils and bedrock. One lake adjacent to heavy blowdown which was extensively salvaged did not acidify, leading the authors to speculate that salvage may partially counter the impacts of blowdown on acidification.

The value of "advance regeneration" in reducing the impacts of natural disturbances may be the critical factor distinguishing actively-managed and naturally-managed watersheds. After disturbance, areas which are quickly occupied with dense, fast-growing seedling/sapling growth will minimize transitional losses of nutrients, and particulate and erosional losses. MDC foresters Buzzell (1991 MDC) and Kyker-Snowman (1989) compared actively-managed and naturally-managed forests with regard to the presence and abundance of advance regeneration. Their findings definitively show that areas which have been actively managed have a much greater amount and density of regeneration and young forest growth. Arbogast (1957) also notes that a key consideration when implementing uneven-aged silviculture on previously unmanaged and undisturbed stands is to enhance age class balance through encouraging development of sapling and pole-sized trees.

The impact of actively-managed and naturally-managed forests adjacent to stream channels is discussed thoroughly in Maser et al. (1988). Although this study is focused on forests of the Pacific Northwest, some principles are applicable to the northeast. The authors documented that streams flowing through young forests and those recently harvested contain only 5-20% of the large woody material found in streams flowing through naturally-managed forests. The stability and length of wood pieces is also increased in naturally-managed forests. While the authors document a clear difference in the fish habitat of the two streams, they also note that the increased debris in streams bounded by naturally-managed forests may impact the stability of streams.

While it may seem that large amounts of woody debris would increase the amount of decomposed material in streams, wood in direct contact with water decomposes very slowly. The authors note that only 5-10% of a stream's nitrogen supply is derived from rotting instream debris. On the positive side, debris serves to create hundreds of dams which slow the flow of particulate material down the stream. The authors speculate that stream stabilization after floods is accelerated by large woody debris, noting that "large stable tree stems lying along contours reduce erosion by forming a barrier to downhill soil movement."

While the conditions in the Pacific Northwest are very different from those in the northeast (for example soils are less stable, forest types are totally different, and forest management systems consist generally of even-aged management using clear-cutting), some of the above material is applicable to the northeast and to MDC watersheds. Bormann et al (1969) in a study of a small watershed in the White Mountains of New Hampshire noted that 1.4% of the watershed was included in the actual stream channel and that debris pools occurred every 1-3 meters. They speculated that these pools served to slow the movement of suspended material from the watershed and reduce the erodibility of the system. Bormann et al (1974) note that in mature forests the export of particulate material is derived from material stored in the stream bed. However, they note that most of this material moves very little, and approximately 90% decomposes slowly in place.

The above discussion highlights the need for careful consideration of lands adjacent to tributaries. In developing management plans for these areas, consideration should be given to the need for stability of the cover type and forest structure, given the potential occurrence of major disturbances. However, the benefits of the slow addition of natural wood-fall to these areas, and the erosion impediments and the stream pools created by this material, should also be analyzed. In assessing the management of stream buffers, Stone (1973) recommends careful thinning of buffer strips as often preferable to complete non-disturbance, as such thinning will limit the amount of debris falling directly into streams. Vellidis (1994) found that forested riparian strips next to agricultural lands took up and removed nutrients in soil and vegetation, preventing agricultural outputs from reaching streams. The author recommends that these forested strips be harvested periodically to ensure a net active uptake of nutrients, if they are to serve as an effective nutrient buffer.

2. Even-Aged Silviculture

a. Water Yields

Beginning at Wagon Wheel Gap in Colorado in 1911, experiments relating forest removal to water yield increases have been conducted at a number of small watershed locations throughout the U.S. Since 1940, three U.S. Forest Service Experimental Forests have supplied the bulk of the data for eastern U.S. applications. These forests are Hubbard Brook, NH, Fernow, WV, and Coweeta, NC. Experiments have included a wide variety of approaches ranging from clearing of small watersheds to patch, partial, and riparian cuts. Most experiments are "paired watershed" studies, where two small, adjacent or similar watersheds are studied; one watershed is treated silviculturally while the other is left intact, as a "control."

Experimental findings show several general trends. However, variation due to site conditions such as slope, aspect, soils, geology, cover type, and additional factors make exact prediction of water yield increases difficult for a given site. Douglas (1983) notes that yield increases can be predicted within 14% of actual values. Federer and Lash (1978) developed a small watershed computer model aimed specifically at predicting water yield increases from forest management of small watersheds in the northeast, using input variables of precipitation, temperature, latitude, slope, aspect, cover type, and soils. This model was applied with a reasonable degree of accuracy to the Cadwell Creek watershed at Quabbin (O'Connor 1982b).

The following general trends emerge from the many watershed experiments that have been reviewed for the Quabbin Land Management Plan:

a.) water yields increase as the percentage of forest cover removed increases - complete removal of hardwood cover on small watersheds can result in first-year yield increases of 4-14 area-inches (total average annual streamflow in the Northeast is approximately 20-25 area-inches or about 50% of total precipitation),

b.) water yields decrease with reforestation of open watersheds and growth of younger forests, with a linear relationship between percentage of watershed reforested and water yield decrease; yield decreases are significant, in the range of 6-7 area-inches lost through significant forest regrowth and forest growth,

c.) water yield increases are greatest the first year after cutting and decline thereafter, usually returning to pre-cutting levels by the 4th to 8th year; most clearing experiments returning to pre-cut levels within 10 years,

d.) water yield increases are generally larger on north versus south facing slopes, with yields up to two and one half times greater for clearings on north facing slopes. One study also showed that west-facing forests used more water than those on east-facing slopes,

e.) differences between cut and uncut watershed yields increase exponentially as annual rainfall increases,

f.) water yield increases from cutting in the many studies in the northeast occurred chiefly during the growing season, with areas of higher snowfall, deep soils, or conifer cover showing larger dormant season increases,

g.) removal of conifer forests will yield more water than hardwood forests, as conifers use more water and snow evaporation is greater in conifers,

h.) conversion of hardwoods to conifers will result in significant losses in water yields - one watershed in North Carolina had a 25% yield loss after conversion of hardwoods to white pines,

i.) greatest yields are usually achieved through removal of riparian vegetation or lower elevation watershed vegetation, j.) much of the increased flow generated from cutting is seen as increases in low flow periods. Increases in peak flows do occur, but are not believed to cause increased flood risk where cutting is implemented on limited areas and moderate increases are generally yielded,

k.) watersheds with deep soils generate longer lasting flow increases after cutting, and yields are more balanced between growing and dormant seasons; watersheds with shallow soils generate yield increases focused within the growing season,

l.) certain early successional hardwoods use measurably more water than late successional hardwoods, and changes in water yield due to shifts in species composition may last in excess of a decade,

m.) yield increases are lower in deep soils and in areas with fast regrowth of regeneration.

(Douglass and Swank 1972, 1975; Douglass 1983; Hibbert 1967; Federer and Lash 1978; Hornbeck and Federer 1975; Hornbeck et al. 1993; Lull and Reinhart 1967; Mader et al. 1972; More and Soper 1990; Mrazik et al. 1980; Storey and Reigner 1970; Trimble et al. 1974.)

Douglass (1983) and Storey and Reigner (1970) emphasize the significance of the above findings as a way to help meet present and future water supply needs in the eastern United States. Given the above summary, the types of management which will yield the most water are those consistent with even-aged management, especially involving large clear cuts.

While clear cutting of entire reservoir watersheds is not feasible for water quality reasons (see next section on water quality), judicious rotation of clear cuts may provide significant flow increases, especially during the growing season when they are most needed by water supply managers. Douglas and Swank (1972) summarize the value of forestry for water supply managers:

> We can conclude from the experimental watershed evidence in the Appalachian Highlands that cutting forest vegetation has a favorable impact on the water resource by supplementing man's supply of fresh water when consumptive demands are most critical. And, the amount of extra water produced can be predicted with a degree of accuracy which is sufficient for many purposes. Although heavy forest cuttings will usually increase some stormflow characteristics on that portion of the watershed cut over,

regulated cutting on upstream forest land will not produce serious flood problems downstream.

b. Water Quality

In describing the impacts of even-aged and uneven-aged management upon water quality, most studies reviewed involved either clear cutting (of whole watersheds or in limited blocks or strips - all of which fall under even-aged management) or partial cutting (where part of or most of the overstory is retained). It should be noted that while partial cutting falls under uneven-aged management, variations of the shelterwood cutting system (a form of even-aged management involving removal of the forest overstory in stages) involve only partial cuttings.

The impacts of even-aged management systems upon water quality vary with intensity and location of management, intensity, layout and maintenance of road systems, and planning and supervision of logging and woods roads operations (Lull and Reinhart 1967; Kochenderfer and Aubertin 1975; Hornbeck and Federer 1975). The water quality parameters principally affected by these activities are turbidity, nutrient levels, and stream temperature.

i. Turbidity

Turbidity is affected by soil exposed in poorly planned, located, and maintained road systems and log landings (Kochenderfer and Aubertin 1975). For example, gravel access roads may have an infiltration capacity of .5 inches per hour, while forests have capacities of 50 inches per hour (Patric 1977, 1978). Haphazardly built road systems may utilize 20% of a watershed, while well planned road systems may utilize 10% (Lull and Reinhart 1967). By comparison, Quabbin watershed roads cover approximately 686 acres or 1% of MDC Quabbin lands. In addition to access and skid roads, the total compacted area of a typical logging area including landings may approach 40% (Lull and Reinhart 1972). In comparison, a study of pine thinnings done by MDC watershed crew members and two private loggers under MDC supervision found that total area impacted by logging - including access roads, skid roads, and landings, ranged fr om 14.8% (MDC crew) to 19.6% (private loggers) (Kyker-Snowman 1989b). Stone (1973) reported soil disturbances covering 15.5% of the logged area for selection cutting versus 29.4% for clear cutting in eastern Washington. Reducing the percentage of a watershed in roads was directly linked to sediment export and was seen as critical in reducing sediment in streams in the Pacific Northwest (Dyrness 1965).

Hornbeck et al. (1986) report that increases in soil disturbance means greater erosion. Martin (1988) recommends setting predetermined travel routes for equipment and doing winter logging and using tracked vehicles rather than wheeled vehicles in sensitive areas. Hewlett (1978) recommends avoiding road locations near perennial and intermittent stream channels in order to eliminate impacts.

A study of erosion on New York City's water supply watersheds highlights the importance of protecting road and stream banks from the effects of erosion. This study of the erosion sources at the Schoharie Reservoir estimated that while road banks made up only .22% of the watershed, they were the source of 11% of all erosion. Streambanks, which made up only .44% of the watershed were the source of 21% of all erosion (S.U.N.Y. 1981).

Construction of new access roads carries the greatest risk of erosion. Massie and Bubenzer (1974 as cited in O'Connor 1982a) found that 36% of all road erosion in the study area was produced by roads two years old or less, although this category of roads made up significantly less than 36% of all roads. Stone (1973) notes that some turbidity is inevitable with construction and initial use of new roads, but that almost all continuing damage from roads is avoidable by using recommended woods roads maintenance techniques.

A comparison study of graveled and ungraveled forest access roads in West Virginia showed that the application of even 3 inches of gravel reduced sediment losses eight-fold, even though the gravel road carried two times the traffic of the ungraveled road (Kochenderfer and Helvey 1974).

Lynch et al. (1975) traced increased turbidity on watersheds in Pennsylvania to scarified log landing areas. However, Kochenderfer and Aubertin (1975) report that:

> Bare soil exposed by road-building, and to a much less extent by log landings, has long been recognized as the major source of stream sediment associated with logging operations.

Turbidity in a West Virginia watershed which was clearcut was traced to both road erosion and channel scour from heavier runoff (Patric 1976). Channel scour is an impact which is unique to large scale clearcuts or disturbances where peak flows may increase.

Mechanical compaction of soil reduces soil infiltration and reduces tree seedling survival (Martin 1988). Erosion problems result when mineral soil is exposed to rain, especially on areas with long, steep slopes. However, even compacted, exposed soils have high infiltration capacities. The most significant erosion occurs when soil is bared to the

"B" horizon, beneath the organic and leached horizons (Patric 1977).

MDC measured soil bulk density (a parameter which shows soil compaction) on transects through a pine thinning at Wachusett Reservoir. Average soil bulk densities did not change significantly when measured before and after logging done by MDC's crew. Average bulk density before logging was 6.18 grams/cubic centimeter (gms/cm) and 6.21 after logging; 13 gms/cm is considered the level where root penetration is inhibited. Stone (1973) reported that soil compaction varies enormously with soil type, moisture content, frequency of traffic, and type of "packing" impact. He concluded that the key to avoiding erosion from logging is to ensure that protection steps will handle extreme rain events on the most sensitive sites. The careful planning of skid roads is essential.

Cuttings where soils are not disturbed by roads or skidding do not discernably increase turbidity (Kochenderfer and Aubertin 1975; Dyrness 1965; Bormann et al. 1974). In Connecticut, 80 logging locations were checked for compaction, erosion, and stream sedimentation. All such problems were found to be related to the transportation aspects of logging (O'Haryre 1980, as cited in More and Soper 1990). Other studies trace turbidity to erosion from heavily used logging roads, particularly after heavy rain storms and from increased streamflow which caused channel erosion (Patric 1976; Pierce et al. 1970 as cited in More and Soper 1990).

Turbidity measurements were compared on watersheds in the Fernow Experimental Forest, West Virginia; treatments included a commercial clearcut, a silvicultural clearcut, and one watershed with no cutting. Turbidity (in Jackson Turbidity Units - JTU) during logging was 490, 6, and 2 units respectively. One year after cutting, turbidity was 38, 5, and 2 units respectively (Kochenderfer and Aubertin 1975). Douglass and Swank (1975) concluded that well planned, well maintained road systems do not damage water resources. In a comparison of logging with planned and unplanned skid trails, the planned logging had turbidity of 25 JTU while the unplanned logging had 56,000 JTU (Reinhart and Eschner 1962, as cited in Brown 1976). A comparison of regulated and unregulated logging in 1947-8 found that unregulated logging increased turbidity 10-20 times background levels while regulated logging increased turbidity only slightly (Douglass and Swank 1975).

In a study at Hubbard Brook, New Hampshire, a watershed was logged with a strip cut even-aged method. In the two years during and after logging, 6 of 147 streamwater samples exceeded 10 turbidity units (Hornbeck and Federer 1975). A study of different stream crossing techniques in the MDC Ware River watershed found that temporary bridge crossings caused less impact than ford crossings or crossing on poles. Increases in turbidity caused by temporary bridge crossings were not measurable beyond 100 feet downstream from the bridge (Thompson and Kyker-Snowman 1989).

Clearing of riparian areas has been associated with increased turbidity (Corbett and Spencer 1975). Lynch et al. (1975) compared middle slope clear cuts with lower slope clear cuts and found turbidities of 4 part per million (ppm) on middle slope cutting, 196 ppm on lower slopes, and 2 ppm on an uncut control watershed.

While useful predictive models exist to estimate soil loss from agricultural practices, few soil loss predictive models exist for silvicultural operations. Burns and Hewlett (1983) developed a model which evaluated clearcut, disking, and planting operations in the southeastern U.S. This model is based on the percentage of bare soil after logging practices and the location of bare soil areas with regard to perennial stream channels. The authors recommend keeping any exposed soil areas away from wet and dry stream channels, in order to minimize erosion. Currier et al. (1979) developed a procedure for analyzing water quality impacts from forest management. Larson et al. (1979) began assembling existing data into a system of computer models. Li et al. (1979) developed a sediment yield model based on the Universal Soil Loss Equation and tested in Colorado.

ii. Nutrients

Logging impacts upon nutrient levels are affected by the amount of cover removed, type of cover removed (hardwoods are more susceptible to nutrient increases), watershed gradient (higher gradients are more susceptible to nutrient increases), location within the watershed (lower areas cause faster nutrient input, but higher areas cause more nutrient loss), timing of regeneration response, and soil type and depth (e.g. deep, poorly-drained, fine-textured soils tended to bind free nutrients before they reached the streams) (Bormann et al. 1968; Brown 1976; Carlton 1990; Martin and Pierce 1980; Martin et al. 1984). While turbidity increases are caused by soil disturbance, increases in nutrient levels can result solely from cover removal. For example, at Hubbard Brook, New Hampshire all trees on a catchment were cut and left on the ground and herbicides applied to prevent regrowth. As a result, stream concentrations of several ions increased significantly (Douglass and Swank 1972). In this study, nitrates increased more than forty times background amounts (Bormann et al. 1968). Cuttings associated with significant nutrient increases typically involve clearing of large percentages of watersheds. However, even clearing of entire watersheds at Fernow Experimental Forest and Pennsylvania State Experimental Watersheds did not appreciably increase nitrates (Kochenderfer and Aubertin 1975; Lynch et al. 1975).

Nutrient increases from cleared areas are derived both from the increases of nutrients released as the decomposition process increases in sunlight and by the reduction in uptake due to the loss of plant cover (Vitousek 1985). At Hubbard Brook, New Hampshire, strip clear-cutting of one third of a watershed caused nitrate increases of nearly two times an undisturbed watershed and one third that caused by a watershed which was completely clear-cut (Hornbeck et al. 1975). The coarse-textured soils of New England which have a lower nutrient-holding ability may be more susceptible to nutrient losses, particularly in areas without plant cover (Hornbeck and Federer 1975). Sites with shallow bedrock, thin unincorporated humus on infertile soil, and coarse skeletal soil on steep slopes are also susceptible to nutrient loss (Williams and Mace 1974). In areas where soils may be sensitive to nutrient loss, limiting cutting to light partial cuts may be necessary to prevent nutrient loss (Brown 1976).

Aber et al. (1978) modeled changes in forest floor biomass and nitrogen cycling using various regimes of clear-cutting. A projected rotation which clear-cuts a forest each 30 years versus one on a 90 year cycle will accumulate less floor biomass and release more nitrogen to streams. Williams and Mace (1974) state that, in general, the more drastic the manipulation of the forest, the larger the corresponding release of nutrients, with minor manipulations causing little or no nutrient release. In their study of jack pine clear-cutting in Minnesota, summer logging involving whole tree removal was found to cause significantly more nutrient leaching than winter logging with only stem removal.

iii. Temperature

Stream temperature is important in protecting aquatic life and because of its impact on dissolved oxygen and nutrients (Brown 1976). Stream temperatures vary depending on the presence of forested buffer strips adjacent to stream channels (Hornbeck et al. 1986). Douglass and Swank (1975) concluded that "stream temperatures are not increased by forest cuttings if a buffer strip is retained to shade the stream."

Kochenderfer and Aubertin (1975) found that clear-cuts on upper watershed areas did not increase stream temperature, as few stream channels occur in these areas. In lower watershed cuttings where trees were left adjacent to the stream channel, cuttings had no influence on stream temperature.

iv. Summary

Studies indicate that erodibility of a watershed impacted by either natural disturbances or logging will remain low "as long as destruction does not involve severe and widespread disruption of the forest floor" (Bormann et al. 1974). The relevant components of logging operations are skidding, log landing, and access road construction, where mineral soil may be exposed.

While increases in streamwater nutrients vary by type of cutting and watershed characteristics, the two key aspects of cutting that influence nutrient release are the location and amount of clearing and the response of forest regeneration. Even where openings are revegetated within four years by rapidly growing early successional species, nutrient losses can occur (Bormann et al. 1974).

Studies have demonstrated the methods that will hold water temperature and turbidity increases within tolerable limits (Swank 1972). Patric (1978) states there is overwhelming evidence that neither the productivity of soils nor quality of water are substantially lessened during or after responsibly managed harvests. Stone et al. (1979) report that if proper precautions are taken, water quality impacts from logging are essentially nil. Regarding timber harvesting, Stone (1973) concludes that "adverse impacts can be greatly reduced or entirely avoided by skilled planning and sufficient care."

3. Uneven-Aged Silviculture

a. Water Yields

While most of the trends summarized in the even-aged management water yields section above also hold true for uneven-aged management, the effects upon water yield vary. For example, uneven-aged management on north-facing slopes, removing conifers and involving significant percentages of basal area, will probably result in higher water yields than less intensive cuts removing hardwoods on south-facing slopes. However, either approach to uneven-aged management will likely result in smaller water yields than a comparable even-aged management approach. This is due to less dramatic changes in soil moisture and evapotranspiration caused by the partial cuttings and smaller openings used in uneven-aged management. These smaller gaps are more quickly filled by adjacent vegetation and advance regeneration. In addition, adjacent trees utilize part of the additional soil moisture created by cutting. Hunt and Mader (1970) found that when two white pine forest plots at Quabbin Reservoir were thinned by 30% and 80%, soil moisture increased slightly to moderately and growth increased by 70% and 230% respectively. Hornbeck et al. (1993) reported that when 24% of a basin was cut in one clearing it yielded twice the water of a similar basin where 33% of the forest was removed in scattered openings.

Douglass (1983) found that "partial cuttings were not as efficient for augmenting water yield as were complete cuttings." Storey and Reigner (1970) note:

> There are several ways we can manipulate vegetation to effect a water savings. The obvious one is by heavy cutting of trees, thereby removing

> rainfall intercepting surfaces and removing the transpiring agent. According to considerable evidence our people have collected, single tree selection cutting saves little or no water. The cutover area need not be large; cutting in blocks or strips or even group selection of trees to be removed will save water.

While it is clear that silvicultural systems employing partial cuttings yield less water than complete cuttings, partial cutting studies do show increased yields (Mrazik et al. 1980). For example, of the 10 selection cut or thinning watershed experiments in the U.S. listed by More and Soper (1990), 8 resulted in significant yields. The average annual significant yields for each of the first five years after cutting ranged from .4 to 2.3 area-inches. When the ten experiments are averaged, selection/thinning resulted in a yield of 1 area-inch per year for the first five years after cutting. Hibbert (1967) reported results of seven selective cuttings in North Carolina and West Virginia with all watersheds except one having a southerly exposure. The average annual yield for years measured after cutting was 1.13 area-inches. The lightest cuttings necessary to produce significant yields remove approximately 20% of the forest basal area (Kochenderfer and Aubertin 1975, as cited in More and Soper 1990; Trimble et al. 1974) . Douglass and Swank (1972) assembled a model which predicts first year water yield increases based on reduction in forest basal area. This model predicts that a 30% reduction in basal area will increase yields approximately 2-3 annual area-inches.

In predicting the significance of water yields to be derived from uneven-aged management, specific site characteristics of watersheds must be examined. For example, cuttings on north facing watersheds with deep soils will result in relatively larger yields. Using regression lines from Hibbert (1967), a one-third reduction in forest cover on a north facing watershed is estimated to yield three times the streamflow of a similar cut on a south facing watershed.

Yields from uneven-aged management should also be viewed in comparison to the two above alternatives: even-aged management and natural management. When compared with these two options, uneven-aged management falls between the two. For example, partial clearing of watersheds with even-aged management may yield 5 or more area-inches per year (approximately 25% increase in yield) for the first few years after cutting (estimated from Hibbert 1967). However, aging forests or naturally-managed watersheds with new forest growth will have reduced water yields over periods without disturbance. For example, Hibbert (1967) reports on three small watersheds (all less than 2,000 acres) in New York where an average of 47% of the watersheds were planted to conifers. After 25 years, the three watersheds averaged 5.3 area-inches less streamflow. Another medium sized watershed (over 300,000 acres) which was passively managed for 38 years and on which average basal area doubled, showed a decrease in runoff of 7.7 area-inches -

equivalent to a 25% reduction.

Thus, existing data show potential water yield increases of approximately 25% for even-aged management and potential decreases on unmanaged forests of up to 25%. Uneven-aged management falls in between these two approaches, but averages small yield increases (on the order of approximately 5% for the first few years after cutting). The above approximate range would be reduced in actual magnitude depending upon the percentage of the watershed cut and the frequency of the rotation of cuttings. However, the relative comparison of the three alternatives should generally hold true. At Quabbin watershed, the mature forest cover would probably produce fairly consistent yields under a naturally-managed approach, and small to moderate increases under either an uneven-aged or even-aged approach.

b. Water Quality

Many of the principles underlying the potential for water quality impacts as a result of logging operations apply equally to even-aged and uneven-aged management. In order to avoid repetition, only the potential water quality impacts unique to uneven-aged systems will be reviewed in this section. As with even-aged management the impacts upon water quality vary with intensity and location of management, intensity, layout, and maintenance of road systems, and planning and supervision of logging and woods roads operations (Lull and Reinhart 1967; Kochenderfer and Aubertin 1975; Hornbeck and Federer 1975).

Uneven-aged systems remove single trees and small groups of trees, leaving a nearly unbroken forest canopy at all times. In a temperate-region forests study of gap-size impacts on nitrates, Parsons et al. (1994) measured extractable nitrate in soil plots. Within a lodgepole pine forest in Wyoming, gaps were created by removing 1, 5, 15, or 30 trees. The authors found that, compared with adjacent undisturbed forest, gaps created by removing 1 or 5 trees had no increase in nitrate. The 15-tree gaps had higher nitrate levels, and 30-tree gaps had nitrate levels 2-3 times higher than the 15-tree gaps. This same stand was previously thinned with no increase in nitrates, and clear-cut with soil nitrate increases of 10-40 times adjacent undisturbed forest. The authors recommend selective harvesting if nitrogen availability is of concern on a site. Stone (1973) notes:

> Any management practices that reduce vigor of the residual vegetation or delay regrowth and regeneration - such as scarification, excessive herbicide application, or maintenance of excessive deer herds - could increase loss rates [nitrate leaching] above those observed on the harvest clearcuts. On the other hand, greater surface soil shading, as by partial cutting methods,

> narrow stripcuts, increased cover density on clearcuts, or any means of hastening regrowth, would reduce losses [nitrate leaching] even more.

Trimble et al. (1974), in comparing management systems, state that water quality is ordinarily maximized on forest land by maintaining an unbroken tree and litter cover. The city of Baltimore's forest management utilizes the selection system because "although this [the selection system] is not the most economical system of cutting to use, it leaves sufficient cover to protect the watershed..."(Hartley 1975).

The literature clearly reports that where stream shading is unaffected, stream temperature will not change (Douglass and Swank 1975; Hornbeck et al. 1986; Kochenderfer and Aubertin 1975). With little significant impact upon temperature and nutrient streamwater parameters, the chief potential impact of uneven-aged management systems is turbidity. However, increased turbidity appears to be less of a concern with uneven-aged management, due to the lighter cutting practices and the amount of forest cover. For example, a comparison study of two watersheds at the Fernow Experimental Forest in West Virginia showed only slight elevations of particulates after three selection cuts during the 1950's and 1960's (cuts included 13%, 8%, and 6% of basal area) as compared to an adjacent undisturbed watershed. In a separate study, Corbett and Spencer (1975) reported no turbidity increases from a thinning operation.

One area of potential concern regarding traditional uneven-aged systems is that cutting cycles are often more frequent, meaning more frequent forest entry and more miles of access roads in use at any given time (Stone et al. 1979). However, the actual impacts will depend upon the uneven-aged method adopted. For example, in uneven-aged forests managed for water supply purposes, trees can be grown on longer rotations and longer cutting cycles. Rhey Solomon, water resource manager for the U.S. Forest Service notes "...the way to keep the water flowing and safeguard the forest is to rotate management throughout the watershed" (American Forest Council 1986).

F. IMPACTS OF AIR POLLUTION UPON THE FORESTS AND WATERSHEDS OF THE NORTHEASTERN U.S.

The intent of this section is to look at the impact of air pollution on present and future forests of the southern New England region. For water supply purposes, managers must consider both the forest as an ecosystem and its function as a watershed. The focus must include both the direct impacts of air pollution upon watershed forests and the impacts of resulting ecosystem degradation upon water quality.

While the following discussion outlines specific impacts of air pollution upon forests, it is extremely difficult to isolate these impacts from the many other processes and stresses occurring in forest ecosystems (climatic stresses, insects, diseases, fire, ice, wind, etc.). It is also difficult to isolate the impact of one specific pollutant, e.g. ozone or nitric acid, from the composite of impacts affecting a forest. Klein and Perkins (1988) state:

> It is now recognized that no single causal factor is responsible, but that there are a variety of anthropogenic causal factor complexes interacting with natural events and processes that, together, induce stresses in forests that culminate in declines of individual plants and of ecosystems.

1. Acid Deposition

Carlton (1990) contains an excellent overview of the impact of acid deposition upon watersheds. In Massachusetts, data indicate that the average pH of precipitation is 4.2; six times more acidic than uncontaminated precipitation (Godfrey 1988, as cited in Carlton 1990). In New England, approximately 60-70% of the acid falls as sulfuric acid and 30-40% as nitric acid (Murdoch and Stoddard 1992; Rechcigl and Sparks 1985, as cited in Carlton 1990). Murdoch and Stoddard (1992) note a study in Maine that showed the sulfuric acid component decreasing in recent years, while the nitric acid component is increasing, leaving the pH of precipitation fairly constant. For example, Stoddard (1991) reported that sulphate deposition had decreased by 1.8% from 1970 to 1984 in the Catskill Mountains of New York. However, the acidity remained the same due to equal increases in the nitric acid component. In Massachusetts, depositions amount to .3 to .7 pounds of hydrogen ion, 16.2 to 27.5 pounds of sulfate, and 8 to 22 pounds of nitrate per acre per year (Petersen and Smith 1989).

Sulfuric and nitric acids tend to accelerate replacement of aluminum, calcium, magnesium, and other base cations in the soil with hydrogen ions (Hovland et al. 1980, as cited in Carlton 1990). In this way, acid deposition will increase soil acidity and directly impact biological activity, soil fertility, and cation-exchange capacity (Carlton 1990). Acid precipitation can also leach aluminum directly into streams causing potential negative water supply and aquatic and fish impacts (McAvoy 1989). Key factors in determining the susceptibility of watersheds to acid inputs include the supply of base cations in soils, the percentage of base-rich groundwater flow versus storm flow, the importance of snowmelt runoff, the average storm rainfall intensity, volume, and duration, and the soil depth, texture, pH, and cation exchange capacity (McAvoy 1989; Peters and Murdoch 1985; Veneman 1984). Records at Hubbard Brook, New Hampshire show that while sulfate inputs have declined, base cation inputs from precipitation have also declined (145 micro eq/liter in 1963 to 104 micro eq/liter 1989) causing sensitivity to acidification to actually increase (Driscoll et al. 1989). The authors attribute the decrease in base cations to a large reduction in suspended particulates since 1970 due to reduction of coal and open burning emissions.

Some researchers have questioned the extent of the impact of acid precipitation. For example, Krug and Frink (1983) feel that most aluminum in runoff is due to acid soils (caused by natural humic acids) not acid rain. Krug and Frink (1983) and Veneman (1984) note that runoff can become more acidic as the acid humus layer increases with forest age and because thick humus layers may reduce the amount of water percolating into the subsoil and increase surface runoff. Studies in Connecticut and the Berkshires of Massachusetts show that soil acidity increases with forest age (Art and Dethier 1986; Krug and Frink (1983). In Connecticut, litter pH changed from 5.5 to 3.9 from 1927 to 1980 and the mineral soil pH from 5.1 to 4.6 during this period. A study in Norway also concluded that changing land use and consequent vegetational succession was largely responsible for acidification of soils and water Krug and Frink (1983).

Reuss and Johnson (1986) identified the key difference between natural and anthropogenic acid inputs as the ability of the stronger nitric and sulfuric acids to leach through to stream waters, whereas the weaker natural organic acids will leach from upper to lower soil horizons, acidifying soils but not stream waters. Therefore, a key factor in identifying systems acidified by pollution is whether pH is attributed to organic acids or sulfates and nitrates.

Driscoll et al. (1988) noted that the "acid rain" and "acid soil" argument is largely due to the lack of long-term data on basin soil and water quality. To help resolve this controversy, the authors compared two similar basins, one in New Hampshire (NH) where acid deposition is significant (pH 4.1) and one in British Columbia (BC) where acid deposition is insignificant (pH 5.0). The basins have similar bedrock, glacial history, and soils but differed in vegetation type and precipitation amounts. Both headwater streams were acidic. The key difference was that the BC stream was dominated by weak organic acids, had low aluminum concentrations, and low sulfate loading, while the NH stream was dominated by strong acids (nitric and sulfuric), had high aluminum concentrations, and high sulfate loading.

Two streams in the Quabbin watershed, the West Branch of the Swift River and the East Branch of Fever Brook, received similar analysis to those in NH and BC (Rittmaster and Shanley 1990). The concentrations of sulfate and hydrogen ion in precipitation was significantly higher at Quabbin than at the New Hampshire site. While both Quabbin streams had high aluminum concentrations during high flow periods, Fever Brook aluminum was in an organic form which is not toxic to fish. Fever Brook also had one half the net export of sulfate of the Swift River, as a result of sulfate reduction in the extensive beaver flowage at Fever Brook.

Veneman (1984) rated the ability of the soils of Massachusetts to buffer acid inputs using many of the criteria outlined above. Of the 25 soil types which make up almost all of the MDC lands at Quabbin, only four (all wetland soil types) were classified as "acid precipitation will have no negative impact on water quality," whereas sixteen types are listed as "acid precipitation will have a moderate or significant impact on water quality." Baker (1984) re-measured soil parameters at eight sites at Quabbin which had been measured in 1962. He found that soils had increased in acidity and exchangeable aluminum and were now releasing sulfate, whereas they were adsorbing sulfate in 1962. These changes have reduced the neutralization capacity of the soils.

2. Interaction Between Air Pollution and Forests

Reuss and Johnson (1986) use the term "canopy leaching" for the process where hydrogen ions replace base cations in the forest canopy. Krug and Frink (1983) report that 90% of the hydrogen ions in acid rain at Hubbard Brook, NH are neutralized in the northern hardwood canopy during the growing season (rain pH of 4.1 changed to 5.0 in throughfall). In studies in the west-central Adirondack Mountain region of New York, Peters and Murdoch (1985) noted that throughfall in deciduous forests was less acid than rain, while thoughfall in coniferous forests was more acid than rain.

As the forest flora exist in several layers above and below the ground surface, the accumulation/neutralization which occurs at these various layers tells a great deal about how the forest processes incoming acid deposition. Yoshida and Ichikuni (1989) studied the chemical changes to precipitation as it passed through the canopies of three different types of Japanese forests. They reported that from 49-74% of the total incoming acid deposition was neutralized by the forest canopies, with deciduous oak forests neutralizing the least and cedar forests neutralizing the most. Virtually all of the cations and anions studied, with the exception of the hydrogen ion, increased as precipitation fell through the canopy (the authors studied Ca^{2+}, Mg^{2+}, K^+, Na^+, NH_{4+}, H^+, Cl^-, NO_{3-}, SO_{42-}, and Al). This indicates the process of "canopy leaching" is evident in these forests. The authors note that similar occurrences have been documented in New England by other authors.

Laboratory studies indicate acid precipitation increases leaching of calcium and potassium from vegetative foliage (Smith 1981). In order for the forest canopy to replace the cations and anions lost, similar amounts of these substances must be taken up from the soil. In some cases, acid conditions cause these nutrients to be leached below the root zone where they become unavailable to plants (Klein and Perkins 1988). The net effect of the above processes is to acidify the soils and damage forest ecosystems (Yoshida and Ichikuni 1989).

Increasing acidity of soil water causes leaching of aluminum, an element of increasing concern to water supply managers. Aluminum also damages fine tree roots and inhibits the uptake of calcium, a nutrient vital to plant growth. This situation leads to further imbalance in nutrients and increases susceptibility to drought stress, decline in growth, and increased mortality (Johnson and Siccama 1983, as cited in Art and Dethier 1986; Petersen and Smith 1989; Smith 1981). For example, soil acidity is a potential contributor to increased nitrate leaching from forests (Vitousek 1977). Klein and Perkins (1988) report that temperature, moisture, light, nutrients, and soil factors all contribute to susceptibility to disease. Recovery from winter injury may also be affected by this type of pollution.

According to Klein and Perkins (1988), trees undergoing nutrient stresses may be predisposed to decline when natural and pollution-caused stresses are added. Forests which are damaged by decline go through a process of "reorganization" during which time increased nutrients are leached from the system into tributaries. This increased loss of nutrients may in turn perpetuate the forest decline.

The overall resultant soil acidity will vary relative to air pollution levels, as well as other factors including soil type and horizon, underlying geology, and successional stage of forest cover (Art and Dethier 1986). In general, the soils of the New England region have a low acid neutralizing capacity or "ANC" (Godfrey 1988, as cited in Carlton 1990). Art and Dethier (1986) studied the relationship of land use and vegetation to the chemistry of soils in the Berkshires. Acidity of the upper-most soil layer was positively correlated to species composition and stand age, with stands less than 140 years averaging pH 4.21 and those over 140 years averaging pH 3.92. Several studies verify an increase in soil acidification with successional sequences following agricultural abandonment (Robertson and Vitousek 1981, Thorne and Hamburg 1985, Krug and Frink 1983, all as cited in Art and Dethier 1986). Acidity varied with land use history, with previously pastured lands having significantly lower pH in the upper horizons than previously cultivated lands. The conclusion is that past land use has a significant impact on species composition and overall soil acidity (Art and Dethier 1986). These studies are useful in considering overall differences in chemical processing in various types and ages of forests and in assessing the potential susceptibility of various forests to impacts of acid deposition.

Soil water pH generally decreases deeper into the soil profile. For example, in a study of eight forest soils in central Massachusetts, mean pH in the A and C horizons were 4.39 and 3.58 respectively; an increase in acidity of eight times. Exchangeable aluminum in the A horizons was nearly four times as high as in the C horizons (Baker 1985, as cited in Carlton 1990).

High levels of ozone cause injury to leaf surfaces of sensitive tree species such as white pine, black cherry, and white ash, especially during summer months. Ozone also reduces photosynthetic rates and the supply of carbohydrates to the roots (Petersen and Smith 1989; Reich and Amundson 1985; Smith 1981). High levels of ground level ozone occur at Quabbin Reservoir, with readings recorded at Quabbin Hill sometimes exceeding other state recording stations including those in Boston.

The combined effects of acid deposition and ozone pollution may be contributing to a measurable decline in Massachusetts forests. A statewide study of the Massachusetts forests identified 24,000 acres which show signs of decline, including yellowing leaves, dead branches, and standing dead trees. This represents a 10% increase in forest decline over twenty years ago (Parker 1988). In addition, the growth rate on one third of the red and white pines studied has dropped 20-50% since the 1960's (Freeman 1987). The overall impact of air pollution predisposes trees to insect and disease outbreaks. For example, research shows that air pollution predisposes pine trees to bark beetle infestations and makes several tree species more susceptible to root rotting fungus (Smith 1981).

In Massachusetts, the decline of red spruce and sugar maple has been examined most closely. Studies of red spruce on Mt. Greylock found that this decline involved a combination of factors, including pathogens, insects, and ice, snow, and wind. However, the decline studied was attributable only in small part to these factors. The high acidity of rain and fog, the high soil acidity, and the low soil nutrient content (including low calcium) at these sites point towards air pollution as a chief cause of the decline of red spruce. The study of sugar maple decline also concludes that many trees are in a weakened condition, which magnifies the impact of other detrimental factors (Petersen and Smith 1989).

In addition to acid deposition and ozone pollution, current air pollution contains metals, polychlorinated biphenyls, alkanes, and various polycyclic hydrocarbons and organic acids (Rechcigl and Sparks 1985, as cited in Carlton 1990). Soil and vegetation surfaces are the major "sinks" for pollutants in terrestrial ecosystems (Smith 1981, as cited in Carlton, 1990). For example, the leaves and twigs of an average sugar maple tree 12 inches in diameter will remove the following elements from the air in one growing season: 60 mg of cadmium, 140 mg of chromium, 5800 mg of lead, and 820 mg of nickel (Smith 1981). Klein and Perkins (1988) report that the accumulation of metals affects nitrogen transformations in hardwood forests.

Forest soils serve as sinks for lead, manganese, zinc, cadmium, nickel, vanadium, copper, and chromium; tree trunks also serve as sinks for large amounts of trace metals including nickel, lead, chromium, cadmium, and manganese (Smith 1981; Driscoll et al. 1988, as cited in Carlton 1990). The U.S. Environmental Protection Agency designed a 40-acre "model forest" containing several hardwood species and white pine (Smith 1981, as cited in Carlton 1990). The model predicts that, within five years of planting, this hypothetical forest and its soils would annually remove the following pollutants:

96,000.00 tons/year of ozone
748.00 tons/year of sulfur dioxide
2.20 tons/year of carbon monoxide
.38 tons/year of nitrogen oxides
.17 tons/year of peroxyacetylnitrate.

The net effect of air pollution on a forest ecosystem is a combination of decreased photosynthesis, decreased growth, increased respiration, reduced biomass, and possible reductions in reproduction. These impacts produce a range of symptoms which together are termed "forest decline." The severity of the decline depends on the amount of pollutants, and the species and site conditions involved. An additional impact of air pollution is alteration of forest ecosystem composition and structure, through selectivity of impact. More severe air pollution, and air pollution on naturally stressed sites, serves to simplify the overall make up of the ecosystem and make it less diverse and less stable (Klein and Perkins 1988; Smith 1981). Smith (1981) defines three classes of air pollution impacts:

* Class I: low dosage, where ecosystem serves as a sink for pollutants
* Class II: intermediate dosage causing nutrient stress, reduced photosynthesis and reproductive rate and increased predisposition to insects and diseases
* Class III: high dosage where mortality is widespread and gross simplification of the ecosystem alters hydrology, nutrient cycling, erosion, microclimates, and overall ecosystem stability.

Klein and Perkins (1988) reviewed more than 400 studies relating to forest decline and concluded:

> There are interactions between primary causal complexes and their direct effects and secondary causes and consequences of forest decline discussed here, so that the web of interactions becomes formidable. Nevertheless, a start must be made on these analyses, not only to understand forest decline holistically, but also because of the pressing need to develop concepts and strategies to ameliorate or reverse the imminent collapse of forested ecosystems. Recognizing that species sensitivities to causal factor complexes varies greatly, inevitable simplification of ecosystems will drastically affect their ultimate stability.

3. Nitrogen Saturation

a. Overview

The potential problem of nitrogen saturation, defined as the declining ability of an ecosystem to retain added nitrogen, was only identified in 1981 (Aber 1992). Researchers are concerned that acid deposition may also be adding significant amounts of nitrogen, originating chiefly from nitrogen oxides in air pollution. The effects of nitrogen saturation include elevated nitrate, aluminum and hydrogen ion concentrations in stream water (Van Miegroet and Johnson 1993). Monitoring of nitrates is required for drinking water (standard=10 ppm) because of health effects upon infants and potential formation of carcinogenic biproducts (Skeffington and Wilson 1988). Nitrates can also cause algal blooms in lakes and reservoirs. Excess nitrogen deposition may also effect forest composition and productivity (Aber 1992).

Bormann and Likens (1979b) report a doubling in nitrate concentration in precipitation since 1955. Schindler (1988) reports that deposition of nitrogen oxides have increased much more rapidly than sulfates in recent decades. Ollinger et al. (1994) report that there is a more than twofold increase of wet nitrate deposition from east to west between eastern Maine and western New York state. The authors mapped broad-scale wet and dry nitrogen deposition across the Northeast, with the Catskill region in the highest category (10.34-12.66 kg N/ha/yr) and the Quabbin region in the 7.99-9.16 kg N/ha/yr category.

b. Processes Involved

The processes related to nitrogen saturation are more complex than those related to precipitation inputs of sulfates, mainly because nitrogen can be both an acid and plant nutrient component and because of the complex interactions between soils and plants and the various compounds of nitrogen. In the ammonium form, nitrogen is a nutrient for the plant/soil biota complex. In the nitrate form, nitrogen can be a nutrient for biota but can also be a very mobile and dominant anion involved in base cation depletion and mobilization of aluminum through the soil and into stream water.

A key reaction in this process is that from ammonium to nitrate (nitrification). Others are denitrification (in which ammonium is formed from nitrate) and nitrogen mineralization (the process by which ammonium is formed from inorganic nitrogen in soils). Mineralization is an important process, as the storehouse of nitrogen in soils far exceeds that in the plant system (75-97.5% of nitrogen is in inorganic form in soils) but the nitrogen can be more mobile in the plant system. As long as the soil system delivers an amount of nitrogen less than or equal to the capacity of the plant system, nitrogen is held within the system. Thus, nitrogen saturation requires both the soil and plant systems to be saturated.

The interaction of these three processes - nitrification, denitrification, and nitrogen mineralization - is dependent upon various bacteria, pH levels, season and climate, as well as variations in plant/soil composition. An added complication is the process of nitrogen fixing, by which plants transform nitrogen gas (the most prevalent component of the atmosphere) to nitrogen in a usable form in the soil/biota system. The relative importance of nitrogen fixation is dependent on the composition of nitrogen-fixing plants in the system. Bormann and Likens (1979b) estimate that 70% of the nitrogen store at Hubbard Brook, NH is derived from fixation and the remainder from deposition. In general, predictions of the timing of the onset of nitrogen saturation are limited by the lack of understanding of soil properties and the complex processes at work there (Schofield et al. 1985; Agren and Bosatta 1988; Nadelhoffer et al. 1984; Foster et al. 1989; Aber 1992,1993).

Disturbance of the plant/soil system by natural or anthropogenic events tends to increase mineralization of nitrogen and consequent nitrification in the system. Vitousek et al. (1979) analyzed processes which keep nitrate leaching in balance. These include the accumulation of ammonium in soil solution on cation exchange sites in the soil, and lack of soil water for nitrate leaching. A delay in nitrate movement after disturbance is critical as this allows vegetation to develop and take up much of the available nitrate before it can leach into stream waters.

Van Miegroet and Johnson (1993) summarize the complexity of the nitrogen saturation process:

> This soil condition is the integrated result of vegetation type, age and vigour, past N accumulation history, climatic conditions, current and past N input regime and soil characteristics.

Aber et al. (1989) have developed equations based on field work which can help model the nitrogen cycle using soil litter analysis.

c. *Symptoms and Site Susceptibility*

Aber (1992) describes the characteristics - including annual stream water nitrate trends - of nitrogen-limited, nitrogen-transition, and nitrogen-saturated systems. In general, nitrogen-limited systems have low nitrate loss during snowmelt, high carbon:nitrogen ratios in soil litter, and high soil dissolved organic carbon concentrations. Nitrogen-saturated systems exhibit the reverse conditions for these three criteria. The identification of elevated nitrates in storm events, especially during snowmelt, may be a first indication that system inputs are exceeding capacity, at least temporarily. For example, researchers at the New York City water supply watersheds in the Catskills are concerned about peaks of nitrates in the spring (up to 128 micro eq/l) combined with elevated summer levels (Murdoch and Stoddard 1992). Rittmaster and Shanley (1990) in studying two tributaries at the Quabbin reported that nitrate concentrations were generally low, but nitrate peaks of 20 and >35 micro eq/l were reported in the two streams during the snowmelt period. The authors attributed these peaks to short soil contact time during storms. There are no other records of nitrate peaks at Quabbin, but limited storm sampling has been done.

Brown et al. (1988) recommend consideration of vegetation type and age, site history, carbon:nitrogen ratios in soil organic matter, external inputs, and nitrogen turnover rates to thoroughly evaluate the condition of a system with regard to nitrogen saturation. The authors note that because natural plant communities change, nitrogen saturation is a "moving target." Van Miegroet and Johnson (1993) reported that forests with small soil nitrogen pools, due to either limited accumulation history or frequent disturbance such as fire, generally have low nitrification potential and insignificant nitrate leaching, irrespective of age or vigor of the forest. Sites that have high soil nitrogen content coupled with a low carbon:nitrogen ratio have a high nitrification potential, and under these conditions the annual leaching of nitrates is strongly dependent on atmospheric inputs, forest age and tree nitrogen uptake rates.

d. Impacts of Forest Succession and Disturbance

Many authors feel that stand age is an important factor in determining nitrogen uptake and annual nitrogen accumulation rates in tree biomass. A declining trend in nitrogen immobilization as a stand matures may explain why nitrate leaching losses are typically larger in mature versus vigorously growing forests. Long periods without disturbance may allow high nitrogen accumulation and low carbon:nitrogen ratios and increased nitrification potentials (Van Miegroet and Johnson 1993). Hemond and Eshleman (1984) note that both higher plant uptake and microbial immobilization contribute to limiting nitrate losses from temperate zone mid-successional forests.

Murdoch and Stoddard (1992) state:

> In watersheds where forests are accumulating biomass, biological demand for nitrogen is often sufficient to retain virtually all atmospherically deposited and mineralized nitrogen during the growing season and reduces net nitrate release to stream water.

In their analysis of elevated summer nitrate levels in Catskill Mountain streams, Murdoch and Stoddard hypothesize that the older forests in the Catskill Preserve may have a low demand for nitrogen and may therefore be unable to retain all of the atmospheric nitrogen entering the watersheds. The authors are currently engaged in a study of nitrogen cycling in New York City water supply lands in the Catskills, investigating nitrogen input/output in different landscape types and documenting streamwater chemistry changes over short distances (Murdoch, 1993 pers. comm.).

Aber et al. (1991) note that changes in species compositions may effect the ability of a forest to absorb nitrogen. For example, due to longer needle retention, pine takes up less nitrogen than oak or maple. The authors also modeled the timing of nitrogen saturation of a hypothetical forest under different scenarios. For example, forest harvesting (removal of nitrogen) slowed the onset of saturation; ozone pollution reduced net primary productivity and moved the onset of saturation up from 300 years in the future (without ozone pollution) to 50 years into the future (with ozone pollution); and alteration of forest species from low nitrogen-demanding to high nitrogen-demanding species delayed the onset of saturation. This modeling exercise did not examine the impact of forest succession.

G. INSECT AND DISEASE IMPACTS

1. Introduction

This section covers the impact of insects and diseases on the major forest trees and the Quabbin forest community. The nature of the interactions between insects, diseases, climate, site characteristics, plants, and animals are complex and constitute an important endemic as well as epidemic disturbance component in the forest ecosystem.

The insects and pathogens that inhabit the Quabbin forest are a phenomenon over which management can exercise little direct control, other than through host manipulations. These organisms will be present for as long as suitable host plant communities exist. The forest provides a large complex area of various habitats and micro-climates for these organisms to occupy. As the largest and most long-lived of the plants in the forest, trees are repeatedly exposed to and attacked by insects and disease over their lifetime. The forest exerts a direct influence on the organisms that inhabit it, and those organisms can directly or indirectly affect each tree's ability to compete and survive in the forest. Tree species growing on sites to which they are poorly suited are often predisposed to such problems (Anderson and Kaya 1976; Berryman 1986). Climate, pollution, wildlife, and both natural and man-made disturbances can individually or collectively reduce a plant's ability to cope with insects or diseases. (Coulson and Witter 1984).

Insect outbreaks follow various population models and can be predicted in the short term with some degree of success (Speight and Wainhouse 1989). Many potentially destructive populations are kept under control simply because the forest has evolved in their presence and therefore has developed characteristics which limit expansions, such as the production of allelochemical deterrents and the provision of habitat for predators. It is for this same reason that organisms which are imported from other regions, and therefore can expand unopposed by evolved defenses, are of great concern. Once introduced, these non-native organisms attack a host or hosts with little or no natural defense, killing them outright, or weakening them and making them more susceptible to native insects or pathogens (Manion 1981). The introduction of the gypsy moth is an example of this type of imported problem.

The elimination of plants can cause a major reorganization of the structure and functioning of native communities and populations. Introduced organisms themselves form new and complex interactions with native species, thus increasing the potential disruption. For example, the chestnut blight functionally eliminated chestnut from the forest overstory, and limited its development to that of an understory shrub (Manion 1981). The problems associated with introduced insects and pathogens are not limited to the plant community. These organisms may displace or eliminate native organisms and bypass the existing system of evolved controls, with repercussions throughout the ecosystem.

Stable populations and fluctuations on a small scale are not considered a threat to MDC watershed protection goals. MDC silvicultural objectives are based partly on trying to keep insect and pathogen populations in an endemic state and to avoid large eruptive occurrences which threaten entire stands. Given that large, homogeneous blocks of host plants often fuel outbreaks, simply maintaining species and age diversity may provide the most significant protection from such outbreaks. A multi-aged and species-diverse forest can slow pest population buildups by providing habitats for natural enemies of pests, providing alternate hosts, and by reducing the concentration and local extent of preferred host species. Within this framework, relatively minor insect outbreaks and disease infestations are common and occur on a regular basis in the forest surrounding the Quabbin Reservoir. In the endemic state, these populations provide a component of biological diversity, and thus overall ecosystem stability.

Silvicultural operations that encourage trees on soils and sites to which they are best suited limit the opportunity for insect and disease infestations. Healthy, vigorous trees have stronger defenses against insects and pathogens, such as the production of alkaloids or accommodation mechanisms such as the production of surplus plant modules; buds, foliage, flowers, roots, etc. (Coulson and Witter 1984). Competition with neighboring trees is one of the most common sources of stress which can reduce an individual tree's ability to survive insect and disease infestations. The reduction of competition for available resources is one of the principal values of thinning operations.

2. Major forest types and effects of insects and disease

a. Oak Types

The insects and diseases that affect oaks are often problems for all oak species. The growth habits and site requirements of each species, coupled with environmental factors, affect susceptibility to insects and disease. Gypsy moth (*Lymantria dispar*) has continued a cycle of outbreaks once each 7 to 10 years on the watershed, each outbreak lasting 2 to 3 years before collapsing. Chestnut oak stands on dry thin soils are often the most seriously defoliated, but large scale defoliations in all oak dominated stands are still possible. Limited control of large gypsy moth populations through infection by the fungus *Entomophaga maimaiga* has shown promise for natural control, but infection and spread of the fungus in gypsy moth populations is not certain and depends on weather conditions.

The oak leaf tier *Croesia semipurpurana* and oak leaf skeletonizer *Bucculatrix canadensislla*, both defoliators, are also common in these oak-dominated stands. These defoliations, if not immediately fatal, set the stage for a continuing downward spiral for trees in susceptible stands. The weakened trees are often attacked by secondary insects or pathogens such as the two-lined Chestnut Borer (*Agrilus bilineatus*) which mines in the phloem and girdles the tree, weakening it further. Shoestring root rot (*Armillaria mellea*), usually a weak saprophyte, is a very aggressive root pathogen in these weakened and susceptible stands. Site-specific disturbances to stands of black and scarlet oaks have caused a high infection rate by cankers and heart rots (*Nectria spp., Strumella spp., Sterum gausapatum*) due to disturbance history, fires, or high stumps on logged lots. Nut weevils (*Curculio spp.*) can hinder regeneration efforts in poor seed years by consuming the bulk of the acorn crop.

b. White Pine Type

White pine (*Pinus strobus*) occurs in native stands and in plantations on the watershed. The white pine weevil (*Pissodes strobi*) can kill young trees and the leader on older trees, seriously affecting crown and bole shape and providing an entrance avenue for diseases. These effects are partially controlled through management of the light regimes in which white pine is grown, basically by keeping young stands dense. Minor defoliations by either the white pine sawfly (*Neodiprion pinetum*) or the introduced pine sawfly (*Diprion similis*) have occurred on MDC watershed lands.

In areas prone to wind damage, large amounts of downed material can provide breeding areas for the Pales weevil (*Hylbius pales*) which can attack young trees growing in the area. Slash, if not lopped down to where it can quickly decompose, is also a potential breeding site. The white pine cone weevil (*Conophthorus coniperda*) can cause the total loss of a white pine seed crop. White pine blister rust (*Cronartium ribicola*) is a serious threat to trees of any age, although successful control has been accomplished through interruption of its life cycle by removal of the alternate plant host (currants, gooseberries and other *Ribes)*, most aggressively in the 1930's and 1940's. Shoe string root rot (*Armillaria mellea*) is able to attack pines through root contact with infected hardwood stumps, killing young trees. Root rots and other fungal infections usually associated with pines growing on poorly drained or inadequately aerated sites include the root rot *Heterobasidion annosum* and red ring rot (*Phellinus pini*). Minor problems associated with some sooty molds, spittle bugs, and aphids are common but have rarely caused mortality.

c. *Hemlock Type*

Eastern hemlock (*Tsuga canadensis*) occurs in both pure and mixed stands on the watershed and is affected by two defoliating insects. The hemlock looper (*Lambdina athasaria*) feeds primarily on hemlocks. This insect has recently caused a great deal of mortality in the New Salem and Petersham blocks and is moving south into stands in Hardwick. The cycle appears to last two years, and those trees losing more than 75% of their needles are not likely to recover. The gypsy moth (*Lymantria dispar*) feeds on hemlocks after more favorable foods are gone, so it has seldom attacked large blocks of pure hemlock. Hemlocks in mixed oak stands and smaller stands surrounded by hardwoods have been killed or left with dead tops following gypsy moth outbreaks. The Hemlock woolly adelgid (*Adelges tsugae*) is an insect recently introduced to New England, and can kill Eastern hemlock in one growing season by defoliation. Not currently present on watershed lands, it is found in Connecticut and may eventually pose a very serious threat to hemlock here.

Hemlock germinates best in moist conditions, which exposes it to molds (*Botryis spp.*) which prevent germination as well as damping-off fungi (*Pythium spp.*) which kill seedlings. Several different needle rusts and molds can effect lower limbs in wet conditions but have not proven to be serious problems. Heart rots and decay fungi easily invade through wounds and dead tops and branches, making older infected trees prone to wind breakage. Porcupines, deer and rabbits all use hemlock for food and cause serious damage to young trees, branches, and stems. This can lead to loss of vigor, secondary insect/disease problems, and ultimately, death.

d. Conifer Plantations

Quabbin conifer plantations consist of red and white pine, larch, Norway and white spruce, in pure and mixed stands. Monocultures would presumably be at a greater risk to insect or disease problems than would more diverse, naturally occurring stands. The white pine weevil (*Pissodes strobi*) eliminated white pine in some mixed plantations by preventing it from successfully competing with the interplanted red pine. Other white pine problems are covered under the White Pine Type section (b.) above, and the spruce plantations are generally small in extent and have not suffered serious insect/disease damage. Red pine (*Pinus resinosa*) on the Quabbin watershed experiences minor insect/disease problems for the most part, with one exception. *Heterobasidion annosum* root rot, formerly and commonly known as *Fomes annosus* root rot, spreads through root grafts and wind-blown spores, and localized infections have killed small blocks within red pine plantations. Sanitation cuts that eliminate infected stands, and thinning operations that regenerate stands to more mixed species, will limit infection by this organism.

Other root pathogens and heart rots (*Verticicladiella procera*, *Phellinus pini*, *Gremmeniella abietina*) are present in many of the overstocked plantations, but do not present serious problems for vigorous trees. Continued thinnings will help limit the impacts of these pathogens. Red pine scale (*Matsucoccus resinosae*), a serious insect in Connecticut red pine, has not been a problem for Quabbin stands. Windthrow has the potential to affect large acreages of red pine on the Quabbin, creating breeding areas for a number of pathogens and insects. Control will depend on efficient and timely salvage operations to remove damaged material.

e. Northern Hardwoods

The Northern Hardwood Type describes a mix of several hardwood species commonly found in close association, including beech, white and yellow birch, sugar maple, and white ash. These associations are most commonly found on rich mesic sites, though beech and birch are also found on dry uplands. Root pathogens and insects which have evolved within this plant association can impact more than one Northern Hardwood species.

Beech will continue to decline and be eliminated from the few stands it occupies as an overstory tree, due to the resident beech bark disease. This insect-fungus complex (*Cryptococcus fagisuga*, a scale insect, and the fungus *Nectria coccinea var. faginata*) is deadly to infected trees and no general resistance to this complex has been shown. The fungus was introduced into Canada and has spread south in the beech forest. A prolific sprouter, beech roots continue to send up shoots but these have little chance for ever growing above small pole size material in the presence of the disease. Beech is also susceptible to shoestring root rot (*Armillaria sp.*) when in a weakened condition. Defoliators include the saddled prominent (*Heterocampa guttivitta*) and forest tent caterpillar (*Malacosoma disstria*).

The birches all share insects and diseases, with small differences in susceptibility due to species characteristics. Defoliators include the birch skeletonizer (*Bucculatrix canadensisella*), birch leaf miner (*Fenusa pusilla*), forest tent caterpillar (*Mallacosoma disstria*), leaf rollers (*Sparganothis acerivorana*) and saddled prominent (*Heterocampa guttivitta*). Defoliations make the trees susceptible to secondary insects such as the bronze birch borer (*Agrilus anxius*). Stem cankers and rots (*Nectria spp., Inonotus obliava, Pellinus igniarius*) invade birches through wounds or branch stubs, most frequently in mature stands. Any disturbance or wound to stems, branches or roots can facilitate the spread of spores in these stands.

Sugar maple foliage is attacked by the forest tent caterpillars, saddled prominants, leaf rollers (*Spargenothis spp.*) and the recently introduced pear thrips (*Taeniothrips inconsequens*). Gypsy moths will feed on maples if preferred food is lacking but populations are usually in decline when this happens. Secondary organisms such as the sugar maple borer (*Glycobius speciosas*) open trees to heart rot (*Inoctaus glomeratas*), shoe string root rot and other diseases.

White ash is experiencing a decline in New England which is thought to be due to a combination of stresses, both environmental and pathological. White ash is sensitive to increases in ground-level ozone and is intolerant of large changes in soil moisture, especially drought. Ash yellows mycoplasma is the direct cause of stress in some individuals, but its role in the more general ash dieback is unclear. Weak canker fungi which normally inhabit the bark on lower branches (*Phellinus igniarius*, *Fusicoccum spp.*) are commonly found in dying ash, taking advantage of the weakened condition of individuals in decline. Leaf rollers (*Sparganthis spp.*) are a common foliage problem, along with various foliage diseases and rusts.

f. Red maple type

Ice storm damage is common in many red maple stands, and broken branches provide a common entry point for decay organisms. Red maple is a vigorous stump sprouter, which enables its reproduction but leaves it vulnerable to a variety of fungi which enter through the original stump. Common heart rots and decay fungi include *Phellinus igniarus, Inontus glomeratus, Nectria spp., Strumella spp.*, and *Eutypella spp.* Red maple is attacked by scale insects, including cottony maple (*Pulvinaria vitis*) and maple leaf scale (*P. acericola*). Defoliators include the gypsy moth, the Linden looper (*Erannis tilaria*) and the forest tent caterpillar. Leaf diseases are often present but are seldom fatal to red maple.

H. FOREST MANAGEMENT SYSTEMS AND IMPACTS ON WILDLIFE

The interconnectedness of natural ecosystem components suggests that an action which directly alters one component is likely to have effects on others as well. Since wildlife populations are closely tied to habitat (especially vegetation) conditions, forest cutting and management activities that alter vegetation will have associated impacts on the local wildlife community. This section reviews the available literature on wildlife/habitat associations and the ways in which various forest cutting and forest management approaches can affect wildlife populations.

While some studies have examined specific silvicultural systems, the literature does not always describe the type of cutting in detail, and it is sometimes difficult to ascertain if it was done under a particular silvicultural system or done without the planning and supervision of a professional forester. It should be emphasized that operations conducted on MDC Quabbin lands are forest management activities designed to meet specific silvicultural goals and are supervised carefully by professional foresters.

The evaluation of the likely impacts of land management activities on wildlife requires information and understanding of:

a. the wildlife community and habitat conditions in the area,
b. wildlife/habitat associations, and
c. projections on the probable future changes in habitat conditions, both naturally-occurring and those resulting from management.

Information on the wildlife community and existing habitat conditions are presented in Section II.C.2. of the Quabbin Land Management Plan. Projections of likely habitat changes on MDC lands resulting from proposed silviculture are presented in Section V.C. of that plan.

1. Wildlife/Habitat Associations

Much of the science upon which wildlife biology and management programs are based begins with the premise that generalized habitat associations can be determined for most wildlife species. Simply put, this means that most species are adapted to live and reproduce in certain conditions of food, cover, climate and other environmental factors. These habitat associations form the basis for habitat management programs designed to increase, decrease, or stabilize populations or assemblages of wildlife species. For example, Eastern cottontail rabbits do best in areas of herbaceous and shrubby cover and are seldom found in mature forest stands. Conversely, the barred owl tends to be an inhabitant of mature, dense forests, and is rarely seen in open areas. A management program designed to increase populations of these two species would need to provide both open herbaceous habitats and extensive forest cover in the management area.

Wildlife/habitat associations are not always easily defined. While some species are fairly specialized in their habitat requirements, others are "habitat generalists" occurring over a wide range of habitat types. Examples of habitat generalists include the raccoon and the American crow. Further, some species have preferred or "optimal" habitats but can also be found in other "suboptimal" habitats, albeit usually at lower population densities. The Quabbin beaver population provides a good example of this. In the 1970's, when food and suitable colonization sites were relatively abundant, the beaver population reached its highest density in recent times. In the 1990's however, habitat conditions became much less favorable, and the beaver population has declined to less than one-quarter of its former size.

Some wildlife species have proven to be quite adaptable to changing habitat conditions, and our understanding of their habitat associations has had to change accordingly. For example, until recently, wild turkeys were thought to require extensive tracts of undeveloped and largely roadless habitats. However, they are now frequently observed from well-traveled roadways, picking through backyard gardens or feeding in manure piles on busy farms.

Different studies sometimes produce very different conclusions about habitat associations. These differences may be the result of a number of factors, including the likelihood that there are regional differences in species/habitat associations which we are only beginning to understand. It is also very possible that some species tend to occur in certain habitat types not because they prefer that particular habitat, but rather because some other habitat feature happens to occur in that particular habitat type more so than in others. For example, a gray birch stand with a significant number of older, dying trees might be used by nesting chickadees, whereas a slightly younger stand with mostly healthy trees might not. The chickadee presence would be a function of the cavities present in the dying trees, rather than the fact that those trees happen to be gray birches. Thus, studies of chickadee/gray birch associations in those two stands would produce very different conclusions.

The result of these "inconsistencies" in wildlife/habitat associations is that it is very difficult to generalize about such relationships, especially when trying to apply the results of research in one area to another area where vegetation, climate, development, and other conditions are dissimilar. Thus, attempts to use wildlife/habitat association information for predicting changes in wildlife communities given various management approaches must be tempered by the understanding that those predictions are only educated guesses for many species.

Studies of species/habitat associations usually approach the subject in one of several ways:

a. by individual species, wherein the habitat requirements or preferences of individual species are determined,

b. by groups of species that exhibit similarities in habitat requirements, or

c. by habitat, whereby the general wildlife values of different habitat types are determined.

The individual or single-species approaches generally rely on simple correlation or presence/absence models. Examples include the Habitat Suitability Index (HSI) models used by the U.S. Fish & Wildlife Service, the Habitat Capability (HC) models used by the U.S. Forest Service, and Pattern Recognition (PATREC) models (Berry 1986). Information is generally displayed in matrix form in such models, and organized by successional stage of plant community or habitat type (see for example, Thomas 1979 or DeGraaf and Richard 1987).

The multiple-species or group approach is based on the observation that some species tend to exploit resources in a similar fashion, and thus can be grouped for analytical purposes. This approach is often more economical and statistically less variable than the individual species approach (Block et al. 1986). Examples of this approach include the Integrated Habitat Inventory & Classification System (IHICS) used by the Bureau of Land Management, Thomas' (1979) life-form system, and Community Guild models (e.g., Verner 1984).

Finally, the habitat analysis approach is useful when a manager is interested in determining the likely changes in a wildlife community due to a change in habitat conditions. This approach often builds on the individual species models, utilizing species/habitat/successional stage matrices. For example, the impacts of converting a stand of mature northern hardwoods to a shrub-seedling stage can be determined. The Wildlife Habitat Relationships (WHR) models being developed by the U.S. Forest Service are another example of this approach.

As tempting as wildlife/habitat models are to use in assessing impacts of planned management operations, it must be noted that relatively few models have yet been adequately tested, and those that have sometimes yield poor results. For example, Layman and Barrett (1986) tested HSI models for the spotted owl, marten and Douglas squirrel and found that even though the models were based on what was believed to be good information, they did not accurately predict the occurrence of those species in the test areas. They identified several problems with the models, including their geographic resolution, unexpected variation in life history parameters, presence of predators, and difficulty in obtaining accurate habitat data. Further, most species/habitat models deal with the broad levels of habitat associations (e.g., occurrence in sapling, pole or mature stands), but not the finer levels (e.g., occurrence in multi-aged versus single-aged mature stands), so are of limited use in predicting impacts of such less-intensive management operations.

Within the general framework of wildlife/habitat association models, further breakdowns are possible. For example, Bushman and Therres (1988) found that insectivorous birds depend on a well-stratified forest with good vertical diversity in order to maintain separation of their feeding niches. MacArthur (1958) gives a good example of this with some warblers in the coniferous forests of Maine. Five species typically occupy spruce forests in that area, yet each is adapted to a different portion of the stand: Cape May warblers occupy the upper and outermost branches; black-throated greens center their activity in the dense parts of branches in mid-elevations of the trees; bay-breasteds feed high in the tree but not near the ends of limbs; blackburnian warblers occupy intermediate strata between the bay-breasted and black-throated greens; Myrtle warblers are variable in site selection. Thus, although all 5 species utilize spruce stands, each is adapted to a particular structural component of that forest type.

Generally, habitat selection by breeding forest birds is thought to be largely a function of habitat structure, rather than cover type (e.g., Anderson and Shugart 1974; Crawford et al. 1981). This leads to further difficulty in predicting impacts of forest cutting operations on bird communities since:

a. many wildlife/habitat association models consider forest structure only indirectly (i.e., only as it relates to successional stage), and

b. the elements of forest structure that many species respond to are influenced by a number of factors (including site quality, light conditions, species composition, etc.) and thus are not easily predicted.

In summary, wildlife/habitat models and information may be useful for giving a general picture of the likely implications of management operations, but caution must be used to avoid putting too much emphasis on those predictions. Chambers (1989) points out that there are still large gaps in our knowledge of specific requirements and needs for most wildlife species, and the data that form the basis for many existing models have been obtained from only a few localities within the geographic range of a species, and do not account for differences in habitat affinities related to regional vegetation and/or climate conditions.

Although more work is needed, many studies have evaluated the impacts of forest cutting on wildlife. A number of these are reviewed below.

2. Impacts of Management

Many studies have dealt with the impacts of forest cutting operations on wildlife populations, and these have produced substantial variability in results and conclusions. As more studies are conducted and new information is added to our understanding of wildlife/habitat relationships, it becomes increasingly clear that few generalizations can be made, especially when attempting to apply results from one location to another. Still, there are some consistencies, and at least the main issues regarding forest cutting and forest management impacts on wildlife can be ascertained from a review of those studies.

In this section, research on the wildlife impacts of cutting under various forest management systems (i.e., No Management, Even-aged Management and Uneven-aged Management) on wildlife will be evaluated. However, in much of the literature on this subject, no clear categorization of the relevant management practices can be made. These studies usually refer generically to the impacts of forest management on wildlife, without specifying the nature of that management. Since many of these articles nevertheless contain useful information on this subject, they will be reviewed here under the sub-heading of "Management - General". In addition, some studies identified specific habitat components that affect wildlife occurrence, and these will also be reviewed.

a. No Forest Management

Unmanaged areas have received increasing public and scientific attention in recent years, especially those that may also be thought of as "old-growth" or wilderness areas. However, much of the research on wildlife use of such areas has been conducted in the Pacific Northwest. Not only has relatively little research of this type been done in the northeast, but there is also some question about whether or not large acreages of old-growth forest would even develop in this part of the country, and if so, how long such development would take.

Gore (1986) recorded small mammal use of an old-growth northern hardwood forest in New Hampshire, and found that none of the 8 species studied required the habitat conditions found in old-growth stands. Likewise, Absalom (1988) did not find any songbird species that was unique to old-growth stands. Both authors however, found higher densities of large-diameter trees and/or snags, or greater average humus depth in old-growth stands.

Unmanaged areas have several social and biological values, one of which is their role as control areas or baselines against which the effects of management actions can be measured (Noss 1991). However, the value of these areas to wildlife remains largely unstudied and poorly understood (Schoen et al. 1981). Mannan and Meslow (1984) expressed concern that unmanaged old-growth forests might be necessary for the survival of some species, but acknowledged that little relevant data is available. Despite this lack of data, there is concern that some wildlife species may require particular habitat conditions found only in unmanaged areas. For example, Noss (1991) felt that one of the many biological functions of unmanaged wilderness areas was to provide habitat for species that do not coexist well with humans. However, on public lands, management activities or public access into previously undisturbed areas may effectively generate disturbance. Species requiring old growth forest conditions pose a particular management challenge since their habitat requirements are not well understood, or may not be readily met by traditional forest management practices.

Most studies of unmanaged areas have focussed on the end result of the "management decision to not manage" - i.e., the mature or later stages of forest succession. However, local impacts, site conditions, and natural disturbance patterns can substantially affect the actual habitat conditions in such areas. Indeed, the periodic disturbances experienced in unmanaged southern New England forest stands may effectively preclude the attainment of "old-growth" or "climax" stages in much of that region. Schoen et al. (1981) prefer the term "Shifting-Mosaic Steady State" over "climax" or "old growth." Their term defines a dynamic but relatively constant condition that structurally ranges from openings to all degrees of stratification, and contains representatives of most species, including early-successional ones, on a continuing basis (from Borman and Likens 1979b). Hansen et al. (1991) reviewed a number of studies in unmanaged forests, and concluded that natural disturbances maintained high structural complexity in those stands, and that this complexity promoted overall plant and animal diversity.

Where and when they do occur, unmanaged forest stands may resemble uneven-aged managed ones, with multi-layered canopies and high structural complexity. However, they often have several additional characteristics not normally found in managed stands. Mannan and Meslow (1984) found that unmanaged old-growth stands sometimes contained plots that were similar to managed forest stands, but that managed forest plots only rarely resembled unmanaged old-growth. Schoen et al. (1981) found that old stands in Alaska also had high structural complexity and variability in the horizontal plane. Features included fallen trees in various stages of decay, standing dead trees, and a variety of epiphytes including fungi, mosses, and lichens. Mannan and Meslow (1984) identified the number of large trees and snags, and tree height diversity as two components of vegetation that distinguished old-growth from managed forests.

A number of researchers have found that the wildlife habitat value of old stands is greatly enhanced by the presence of large live trees, large snags, and large logs, both on the land and in streams (e.g., Franklin et al. 1981; Harris 1984). Hansen et al. (1991) found that these attributes were best developed in "natural" (vs. managed) forests and that some of these structures survived catastrophic events, thus enhancing the structural richness and wildlife value of the succeeding regenerating stands. Welsh and Lind (1988) identified the greater structural complexity and the narrower and more stable ranges of moisture and temperature as the important factors influencing herpetofaunal distributions in older stands. The downed logs and other woody material found in old stands was especially important in moderating or buffering moisture and temperature fluctuations, and in providing cover. Bennett et al. (1980) found that a long period of limited disturbance in a South Carolina pine habitat permitted the development of a variety of amphibian niches that would not otherwise exist. Again, decaying stumps and logs, and the development of extensive undergrowth and ground litter, were found to be important factors influencing animal abundance.

b. Management - General

Many studies that looked at animal communities in unmanaged forest stands compared those communities with ones found in nearby "managed" stands, and derived conclusions about the effects of forest management "in general" on wildlife. Frequently, these effects were found to be directly related to structural changes in the stands brought about by the management activity. Thomas (1991) found that managed stands were apt to be more simplified in structure than unmanaged stands. Further, forest management often results in reductions in snags and large fallen logs - both important components of the forest ecosystem (Franklin 1988). On the other hand, forest management can have very beneficial effects on species that respond to the changes in light, overstory and new growth conditions that often result from logging.

Several studies show that managed stands support more breeding birds than unmanaged ones. Mannon and Meslow (1984) found that several species (e.g., hermit thrush, pileated woodpecker, brown creeper) were not found in managed stands, but many others were attracted to the more open structure of the managed stands (e.g., ruby-crowned kinglets, chipping sparrow, mourning dove, several flycatcher species). Harris (1984) found that the number of common or fairly common species, as well as the total number of species, were greater in a partially logged mature stand compared to an unmanaged old-growth stand. Morse (1976) found that several warbler species (e.g., Parula, Cape May, bay-breasted) appear to be dependent upon special conditions that are not continually present in undisturbed forests. Webb et al. (1977) found that species richness, evenness, and overall diversity were all highest on the most intensively-managed northern hardwood plots, and none of the species they monitored was so sensitive to habitat disturbance that it was "driven out" by logging.

Other studies suggest that logging is generally detrimental to breeding birds, although it is clear that the type and intensity of management is an important factor in determining the nature of the impacts. Franzreb and Ohmart (1978) found significantly higher numbers of birds on unlogged versus logged plots, although the total number of species was approximately the same. Brittingham (1989) reviewed the issues of edge effects and forest fragmentation caused by logging, and how they affect breeding bird populations. She notes that even though such activities may result in increased local abundance and species diversity, this increase generally occurs in game species and habitat generalists, some of which are nest predators or parasitizers responsible for declines in forest interior species. Similarly, Harris (1984) found more common or fairly common species and higher species richness, but fewer rare species, in logged versus unlogged old stands in western Washington. Franzreb (1978) found that some species (e.g., ruby-crowned kinglet) may still be present, but show reduced densities or enlarged territories following logging. Other species are more adaptable in their habitat use, and may respond to logging impacts by increasing their niche breadth (e.g., by using tree species not normally used).

It is clear that the response of songbirds to forest management activity is highly variable, and the best way to assess the impacts of logging is by identifying the particular species or group of concern. Franzreb and Ohmart (1978) found that different foraging groups responded in different ways to logging. For example, bark-searching (e.g., brown creeper, pygmy nuthatch) and foliage-searching species were more abundant on unharvested plots, while aerial foragers (e.g., most flycatchers) were more abundant in the logged plots. Crawford et al. (1981) classified songbirds according to habitat features of their selected territories, and found that degree of canopy closure and density of low vegetation were the most important habitat features affecting habitat use by songbirds. Each habitat they studied had a characteristic group of songbirds using it, and changes in bird community composition could be predicted by determining the likely changes in those two habitat variables brought about by logging. Thus, moderate to large clear-cuts resulted in open canopies and brushy understories, and benefited "open canopy obligatory" species such as field sparrows, prairie warblers, and eastern bluebirds. Single-tree selection practices favored "closed canopy" species such as white-breasted nuthatches, ovenbirds, and wood thrushes. Webb et al. (1977) devised a similar classification scheme based on the type of response different species exhibited to logging. For example, American redstart, chestnut-sided warbler, veery and white-throated sparrow numbers were all increased by logging; blackburnian warbler, wood thrush, ovenbird, and yellow-bellied sapsucker numbers decreased following logging; red-eyed vireos, scarlet tanagers, black-throated blue warblers, and black-capped chickadees were not affected. They concluded that the avifauna of the undisturbed northern hardwood forest is not eliminated by logging, but certain elements are favored while others are not.

These studies demonstrate that silvicultural practices cannot be categorically described as beneficial or detrimental to songbirds. Forest cutting may change the habitat enough to decrease populations of some bird species, but other species better adapted to the modified habitat will occupy the site following the change (Crawford et al. 1981). Whitcomb et al. (1977) offered a simplified summary of the expected changes in bird populations following tree removal from a mature forest:

a. overall species richness increases as a result of increased habitat diversity,

b. numbers of canopy-dependent species are reduced,

c. densities of shrub-layer species increase in response to the additional nesting cover created, and

d. if the forest floor becomes entangled with new shrub growth, densities of ground foragers will be reduced.

The net change in carrying capacity of the forest may increase or decrease, depending on the extent of the change and the completeness of the available species pool of potential avian colonists.

Forest management is generally beneficial to a wide range of species that utilize edge habitats and/or the food, cover, and nesting habitat that woody regeneration provides. Numerous studies have documented the increase in browse produced by logging (e.g., Bennett 1962; Knierim et al. 1971; Crawford 1976). Krefting and Phillips (1970) measured substantial increases in browse production following experimental cuttings in Michigan. Selection cuts resulted in a 2 1/4-fold increase, and shelterwood cuts greater than a 10-fold increases in browse weight within 6 years following the cuts. Crawford (1976) also found that woody growth increased with cutting intensity. Frank et al. (no date) predicted positive responses by moose, snowshoe hare, and ruffed grouse to silvicultural treatments in Maine.

Relatively little information is available on the response of small mammals to forest management. Gore (1988) felt that since most small mammals use a wide range of habitat types in the northeast, habitat disturbance should not directly affect population levels. However, Nyberg et al. (1987) reviewed several studies that documented substantial small mammal use of the abundant downed woody material found in unmanaged old-growth forests. Healy et al. (1987) found that small mammal catch per unit effort was slightly higher in unthinned versus thinned forest stands, with little difference in species composition.

A few studies have looked at the responses of amphibians to forest cutting, and these have generally found adverse impacts. Welsh and Lind (1988) cited the results of their own, plus six other studies, that showed reduced abundance and species richness of herptiles following logging. Buhlmann et al. (1988) found that tree removal, particularly clear-cuts, affected terrestrial salamander communities through:

a. reduced moisture-retaining potential of the leaf litter and soil, and the resulting increases in insolation, soil temperature, and erosion; and

b. soil compaction and destruction of the leaf litter.

Pough et al. (1987) noted that the structural and vegetative characteristics of a forest that affect the temperature and moisture regimes of the forest floor are important in determining salamander microclimates and microhabitats. In addition, forest management practices that open the canopy, reduce the density of understory vegetation, or reduce the depth of the leaf litter affect both the abundance and above-ground activity of salamanders. Clear-cutting and other activities that disrupt the leaf litter were particularly deleterious, since the soil/litter interface is an important microhabitat for salamanders. However, their results suggest that woodland salamander populations are resilient to some forest management practices - particularly those that result in only small-scale changes in habitat.

Bennett et al. (1980) reported mixed results in their study of amphibian use of managed versus unmanaged forest stands in South Carolina. They found that a natural (i.e., unmanaged) oak-hickory stand supported a higher number of individual amphibians than nearby managed pine habitats, but found no differences in calculated diversity indices or species richness. However, they do suggest that 24-26 years of limited disturbance in the pine stands permitted the development of extensive undergrowth, ground litter, and decaying stumps and logs and other amphibian niches that would otherwise not exist. They also caution that other factors such as age and size of stand, distance from water, and season of study may influence the results of such studies.

c. *Even-aged Management*

Management of forest stands through even-aged methods (e.g., clearcutting or shelterwood cutting) has traditionally been thought to provide for greater wildlife diversity than other management methods. This thinking arose from the long-held belief that good wildlife management meant providing many different habitat types and successional stages in a patch-work pattern across the landscape. The resulting "horizontal" diversity, with its associated "edges," would provide habitats for many different wildlife species. Although this traditional view has been challenged recently, especially in regards to concerns about forest fragmentation and forest interior species, it is nevertheless true that even-aged management can benefit many wildlife species.

The long-term result of even-aged silviculture is a landscape composed of "blocks" of similar-age trees, at various stages of succession, all progressing towards a mature forest condition. Thus, while vegetational variability within a single stand may be relatively low, variability across the landscape is generally high. These conditions contrast sharply with forests managed under uneven-aged systems, in which "within-stand" diversity is generally high, but "between-stand" variability low. These differences have important implications for wildlife.

The specific habitat conditions in a managed area, and thus its wildlife value, are dependent upon a number of factors, not the least of which are stand age and successional stage. Hurst et al. (1979) found that forage from grasses and forbs declined with increasing forest age, height, and basal area. Thomas (1979) evaluated 6 different successional stages (from "grass-forb" to "old growth") based on a number of diversity and productivity parameters (e.g., plant diversity, forage production, animal diversity, etc.), and showed that these parameters changed significantly as succession progressed. Likewise, Conner and Adkinson (1975) determined breeding bird diversity indices for 6 successional stages following clearcutting in mixed oak stands. They found that shrub-sapling and mature stages contained the highest number of birds and species, and had the highest diversity indices, while the early and pole stages had much lower values. James and Wamer (1982) drew similar conclusions in their review of the relationships between bird communities and vegetation structure. Welsh and Lind (1988) found a similar relationship between stand age and amphibian abundance.

Under even-aged management systems, it is generally easier to maintain a relatively full complement of wildlife species, since a fuller range of habitat types, stand ages and successional stages can be provided. Early-successional species (i.e., those adapted to open fields, shrub-sapling and similar habitats) particularly benefit from this type of management. DeGraaf and Richard (1987) show that of the forest-dwelling wildlife of Massachusetts, 55% of birds, 62% of mammals, and 75% of amphibians and reptiles utilize early successional stages to meet at least some of their annual needs. Thus, even-aged management provides habitat for a number of species that are not usually found in the generally older stands more typical of uneven-aged management systems. DeGraaf (1982) found 54 species of birds using the various stages of northern hardwood stands managed under an even-aged system, in contrast to only 24 species in uneven-aged stands.

Conversely however, species needing large blocks of older, mature forest may be adversely impacted by even-aged management (deCalesta 1989). Schoen et al. (1981) found that even-aged silviculture generally stopped forest development at or below the end of the "aggradation" phase, when forest structure was still comparatively simple. In coniferous forest types, they found that vertical structure at that stage consisted of a dense one-layered canopy, an intermediate stratum of even-aged, even-sized trees, and a forest floor stratum mostly devoid of vascular plants. Although these conditions persist for long periods of time in some regions, the resultant impacts on wildlife could still be mitigated somewhat by extending rotation lengths, thereby allowing more late successional, mature forest conditions to develop.

Even-aged management generally results in infrequent but drastic changes in habitat conditions (i.e., when stands are regenerated), and then more gradual but longer-term habitat changes as the regenerating stands progress through succeeding stages towards a mature condition again. For wildlife, this often means a corresponding drastic change initially, then more gradual community changes associated with the subsequent seral stages. Probst (1979) found that clearcutting and shelterwood cuts usually cause drastic reductions in the avian community population size, and almost complete turnovers in species composition the first growing season after harvest. In the succeeding seral stages however, there is often a fair amount of overlap in species composition. For example, black-and-white warblers may be present in low numbers in seedling/sapling stands, reach their highest abundance in pole or middle successional stages, then decrease somewhat but still be present in mature sawlog stages (Bushman and Therres 1988). This pattern holds true for a number of other bird species as well. Thus, some species have relatively narrow habitat requirements, while others can exist across a wider range of habitats. Since even-aged management can result in a mosaic of different habitat conditions across a landscape, a fairly wide range of bird species are likely to benefit from such a management approach.

Several studies have found that peak songbird populations occur in recently-regenerated sapling stands. Probst (1979) thought this happened within 5 or 6 years following cutting on most sites, though peaks might be reached later in understocked stands. Conner and Adkinson (1975) found that peak numbers of individuals, species and diversity measures occurred between 3 and 7 years after clearcutting. However, in his study of bird communities in northern hardwood stands, DeGraaf (1982) found high species richness in seedling and sapling stages, relatively low numbers in pole stands, and maximum species numbers in overmature stands. Likewise, Balda (1975) stated that late successional stages support greater species diversity due to the vegetative complexity found in those stands.

The response of the wildlife community to the changing conditions resulting from forest management is largely a function of the changes in vegetation and other habitat elements brought about by that management. Clearcutting often eliminates cavity trees and overstory mast production, but as clearcuts in northern hardwood stands grow through the seedling stage, they provide the highest levels of forage, understory mast, and woody stem density (Tubbs et al. 1987). Krefting and Phillips (1970) found a similar relationship in mixed conifer stands. Halls and Alcaniz (1968) measured open-grown plants of seven browse species and found 32 times more fruit and 7 times more twig growth than in plants growing beneath a sawtimber canopy. Moran and Terry (1987) found that clearcutting 50% of management units resulted in high winter and summer use of those areas by deer. Crawford et al. (1975) compared a 10 acre clearcut with a 5 acre selective cut, and found more fruits and almost 5 times more "total foods" per unit area in the clearcut. Such vegetational responses are largely responsible for the high wildlife usage often observed in recently-cleared areas.

A number of adverse impacts on wildlife associated with even-aged management have also been reported. For example, clearcutting can contribute to "edge avoidance" and increased predation rates among nesting songbirds (DeGraaf 1982; Brittingham 1989). In Michigan, clearcutting more than 75% of a management unit resulted in inadequate winter cover and thus lower deer usage of those units. In Maine, clearcutting has evidently deterred bald eagles from using otherwise suitable lakes for nesting (Livingston et al. 1990).

Overstory removal can also be deleterious for some salamander species. Buhlmann et al. (1988) found that clearcutting and its associated disturbances appeared to eliminate populations of the cow knob salamander on their study area. Pough et al. (1987) found that while the eft stage of red-spotted newts was relatively tolerant of heat and dryness, and thus was able to occupy areas where logging had opened the forest canopy, adult red-backed salamanders occurred only in adjacent uncut forest stands.

Gore (1988) felt that clearcutting might alter habitat conditions enough so that species abundance and distribution of small mammals would be affected. However, even large-scale disturbances would likely produce only temporary changes in the small mammal community.

While specific adverse impacts of even-aged management on wildlife populations do occur, the net impact of clearcutting in predominantly forested areas is often considered positive. Tubbs et al. (1987) thought that clearcutting was an important tool for maintaining plant and animal diversity in northern hardwoods. Welsh (1992) found that even-aged management in New Hampshire resulted in increased bird species diversity. Scanlon (1992), after reviewing wildlife habitat needs in Massachusetts, proposed active forest management, including clearcutting, for promoting wildlife diversity in the state.

d. Uneven-aged Management

Uneven-aged forest management systems employ single-tree or group selection methods to stimulate new age classes while still maintaining the integrity of the overstory. On the stand level, this management approach tends to increase vertical diversity and the density and biomass of the midstory and shrub layers, but decrease tree species diversity and overstory biomass (Zeedyk and Evans 1975). In general, shade-tolerant and some intermediate tree species are favored by this form of management; intolerant species are usually poorly represented in uneven-aged stands. Harvesting operations are generally conducted every 10 to 20 years, resulting in more frequent, but less drastic, disturbances than with even-aged management. While some studies reviewed specifically referred to "uneven-aged management" others used terms such as "selective cutting," and while they may be similar to true uneven-aged management, the exact differences were not specified.

On the landscape level, uneven-aged management tends to produce a fairly uniform forest cover, since it provides only one general set of habitat conditions over large areas and for long time periods (Roach 1974). Thus, horizontal diversity is generally lower than that provided by even-aged management, and fragmentation and edge-effect issues are of less concern.

The use of an uneven-aged management system has a number of implications for the wildlife community. Temple et al. (1979) listed these likely impacts to bird communities in mixed forests:

- increased vertical diversity will favor high densities of a few species,
- reduced tree species diversity will tend to depress the overall bird species diversity in the stand,
- the lack of early seral stage habitats will reduce overall species diversity in the region, and
- the more frequent harvesting schedule will cause more frequent disturbance to some species.

Whitcomb et al. (1977) studied the long-term effects of selective logging on birds in

Maryland, and concluded that selective tree removal:

- increased habitat diversity and avian species richness,
- decreased the carrying capacity of canopy-dependent species (e.g., cerulean warbler, blue-gray gnatcatcher),
- increased densities of shrub-layer species (e.g., rufous-sided towhee, hooded warbler), and
- decreased densities of ground-foraging species (e.g., ovenbird).

Adams and Barrett (1976) found that in contrast to an uncut control, in which both tree and bird species compositions were "dominated" by a few species, a selectively-cut stand showed more "co-dominance" and created a more heterogeneous vegetative structure. Even though more resident species were found in the control, the authors concluded that the cut stand provided a more diverse distribution of avian niches.

Probst (1979) found that thinning the forest canopy made it less useful for some insectivores (e.g., gleaners) but created better opportunities for flycatchers and other pursuers. Bushman and Therres (1988) thought that partial canopy opening would benefit species such as the yellow-throated vireo, black-and-white warbler, northern parula and scarlet tanager, but would cause declines in species dependent upon closed canopies (e.g., Acadian flycatcher, ovenbird, American redstart). Declines in these species may be more related to their need for open understories than for closed canopies. Crocker-Bedford (1990) studied goshawk reproduction in selectively-cut and uncut control stands, and found that timber harvesting caused a decline of more than 75% in numbers of nesting pairs. Apparently, goshawk nesting density was closely associated with dense overstories and open understories in Crocker-Bedford's study area.

Gore (1988) felt that small-scale disturbances associated with single-tree or small group selection cutting would likely not affect the species composition or density of resident small mammal population levels in his northern hardwood study site. Crawford et al. (1975) compared the relative values of a clearcut and a selectively cut area as deer habitat. They found that although the clearcut initially produced significantly more browse and other wildlife food, when the entire regeneration cycle and repeated cuttings were considered, the selectively-cut area produced almost twice as much food value and for a much longer time period.

Several studies specifically addressed the impacts of selective cutting on wildlife in the Quabbin Reservoir area. DeGraaf et al. (1991) found that the effects of both thinning and relative deer densities produced distinct differences in vegetational conditions, but did not result in dramatic differences in the breeding bird community. However, the "thinned" forest used in that study did not represent the long-term vertical structure achieved when an uneven-aged system is fully implemented. Although the composition of the bird community differed among the various treatments, unique communities for any treatment category could not be detected. Overall, thinned stands contained more bird species and individuals than unthinned stands. Several species showed differences in abundance in thinned versus unthinned stands; for example, densities of American redstarts, red-eyed vireos and ovenbirds were higher in uncut stands, whereas towhees were more abundant in thinned stands. However, these species were abundant in all treatments and thus considered to be relatively insensitive to habitat manipulation.

Chadwick et al. (1986) also studied breeding bird communities in selectively-cut stands near Quabbin. They found more species and more birds in cut stands than in uncut controls, as well as significant differences in species composition. In general, open-ground species (e.g., ovenbirds, hermit thrush) and cavity-nesters dominated uncut stands and occurred in lower densities on cut areas. Twelve species (e.g., prairie warbler, chestnut-sided warbler, common yellowthroats) were most abundant on cut areas. Chadwick et al. concluded that:

- cutting provided open-canopy and ground-shrub habitats in woodland areas,
- neither the bird community nor vegetation conditions developed or changed in distinct stages as found with even-aged management systems,
- time since cutting did not appear to influence the character of the bird community,
- cutting had negative effects on cavity-nesters, open-ground, and closed-canopy species, but
- because no bird species was eliminated and total bird density doubled, the cutting had a generally positive impact on the bird community.

Healy et al. (1989) found that unthinned stands at Quabbin had about 2.9 times as many cavity trees and 1.8 times as many dead trees per hectare as thinned stands.

e. Specific Habitat Conditions

The above review of studies on the impacts of forest management systems on wildlife demonstrates that while there are some general differences between the various harvest systems, there is also a great deal of variability and inconsistency in the results. This is because some wildlife species respond not to generalized habitat conditions but rather to one or more specific habitat conditions. For example, retention of large snags during logging operations (whether they are part of even- or uneven-aged management systems) can have significant effects on local bird communities. Chadwick et al. (1986) recorded major shifts in bird species composition and relative abundances when snags were eliminated during fuelwood operations. Similarly, Mannan and Meslow (1984) suggested that large snag retention could help mitigate the adverse impacts of logging in old-growth stands. Thus, it is possible to lessen the impacts of forest management on wildlife by understanding and then retaining or creating the habitat conditions that species require.

Several studies have found that "forest type" can be a major determinant of wildlife occurrence. Pough et al. (1987) found that pure conifer stands were inhospitable to salamanders, and that amphibians in general were more abundant in oak-hickory stands than pine habitats in South Carolina. Bennett et al. (1980) recorded over 50% more individual amphibians in a hardwood stand than in either of two pine sites they studied. Gill et al. (1975) also reported higher use of hardwood sites than pine stands by several game animals in West Virginia. Litvaitis et al. (1985) found that the superior cover from predators and climatic extremes provided by dense softwood understories supported higher densities of snowshoe hare than did hardwood stands. Morse (1976) found higher densities of black-throated green warblers in red versus white spruce, and postulated that the different structure of the branches and needles of the two spruce species accounted for the difference.

Sometimes, wildlife appear to seek out specific tree species within a given habitat area. For example, Holmes and Robinson (1981) found that foliage-dwelling birds in New Hampshire showed a preference for yellow birch trees, and an avoidance of beech and sugar maple. In Portnoy's (1974) study of red-shouldered hawks nesting at Quabbin Reservation, birch trees (particularly black birch) were selected at 9 of 12 nest sites.

James and Wamer (1982) studied a number of habitat factors as they related to forest bird communities and found that tree species richness, canopy height, and tree density were all important factors affecting bird density and species richness. The highest bird densities were recorded in forests with high tree species richness and canopy height. Low tree species richness, low canopy height, and high density of small trees resulted in the lowest bird densities and species richness.

Numerous studies have shown that dead wood on the forest floor can play a significant role in influencing wildlife habitat use (see for example, Maser and Trappe 1984; Franklin et al. 1987). This is especially true for species that depend on insects and other invertebrates as a food source. Renken and Wiggers (1989) found that pileated woodpecker territory size in Missouri was inversely related to log and stump volume.

Stand size has been shown to be an important factor for some species of wildlife. For example, Ambuel and Temple (1983) studied bird communities in forest stands in Wisconsin ranging from seven acres to more than twelve hundred acres, and found that forest generalists, edge species, and farmland species occurred in most stands, while many forest-dwelling species occurred only in larger stands. Thomas (1979) found that the maximum number of avian species occurred in habitat blocks or forest stands of 75-100 acres in size; stands smaller than 75 acres lost too many area-sensitive species, while stands larger than 100 acres did not satisfy the habitat requirements of edge species.

f. Summary

Clearly, forest cutting can have significant impacts on wildlife communities. Both even-aged and uneven-aged forest management, as well as the decision to not manage at all, will benefit some species and adversely impact others. Thus, trade-offs are inevitably involved in making policy decisions regarding forest management impacts on wildlife, and the acceptability of those trade-offs can only be determined by relating them to the specific management goals for the area. Zeedyk and Evans (1975) state that nongame bird habitat management alternatives in eastern deciduous forests are numerous, but that the specific objectives of wildlife habitat management plans are often ambiguous or ill-defined. Thus, the first step in evaluating the impacts of any forest management program on wildlife is to clearly define management goals and objectives.

It is generally accepted that forest management has the potential to provide habitat for more wildlife species than unmanaged forests, largely because the early-successional conditions important to many species are lacking in most unmanaged stands (DeGraaf and Richard 1987). Similarly, Hansen et al. (1991) concluded that the early successional herb/shrub seral stage has a structure and composition that differs substantially from all older forest stages, and that many wildlife species are specialized to these habitats. Even-aged management, since it produces a variety of distinct successional stages and a myriad of habitat niches (Thomas 1979), tends to complement a goal of high overall diversity on a local level better than uneven-aged management or unmanaged stands.

Regardless of which forest management system is chosen, silvicultural prescriptions can be modified to preserve, enhance or create certain stand features or habitat conditions to meet specific wildlife habitat objectives (Mathisen 1983). These might include extension of stand rotation length to create "old-growth" conditions, the deliberate retention of snags, mast trees or other unusual or important trees, the modification of stand size or configuration, or various other specific changes in normal operating procedures. Healy (1989) suggested that within a group-selection uneven-aged management program, group sizes of 1 to 2 acres could allow for certain early-successional species to occupy the area. Likewise, even-aged management conducted in large blocks, and with extended rotations, can result in suitable habitat conditions for forest interior and other species not normally associated with that type of management system. Thus, the generalized impacts (reviewed above) that are associated with different forest management systems can be substantially modified and mitigated, given the specific approach employed and the habitat requirements of target species.

I. WATERSHED MANAGEMENT AND GENERAL IMPACTS ON WILDLIFE

The composition and relative abundance of wildlife populations and communities are largely determined by the characteristics of their habitats, especially vegetation. Thus, establishing goals for vegetation conditions will largely pre-determine the nature of the eventual wildlife community living in a given management unit. Oftentimes, land use and/or habitat management will influence the relative abundance of species, rather than species composition. For example, in the early 1800's, when much of southern New England was openland, the relative abundance of "forested" versus "openland" wildlife species was very different than it is now; however, the species richness (i.e., the number of different species present) during those two time periods was probably very similar. Only rarely have actual species composition changes occurred in this region, and those cases have usually involved the loss or addition of species as a direct result of human intervention (e.g., uncontrolled hunting, or re-introduction efforts).

Still, habitat changes resulting from land management activities can have substantial influences on wildlife populations, even if they do not cause actual changes in species composition. Land managers must understand these influences so that unintentional impacts can be averted. The general nature of the influences of various land management practices on wildlife communities is discussed in this section; predicted impacts of specific aspects of MDC management plans are addressed in Section V.C. of the Quabbin Land Management Plan.

Three aspects of wildlife communities and habitats have received widespread attention recently, and will be addressed here: a) "biodiversity," b) "forest fragmentation" and the resulting impacts on forest interior and edge species, and c) "wildlife corridors." Each of these issues has been the subject of much controversy and concern among ecologists, managers, and the general public, especially when global or landscape-level situations are considered.

1. Impacts upon Biodiversity Given Various Management Systems

The term "biological diversity," often shortened to "biodiversity," refers to the variety and variability among living organisms and the ecological complexes in which they occur (Office Technol. Assess. 1987). Much of the concern regarding biodiversity involves the rapid rate at which individual species are disappearing and the very real possibility that entire ecosystems will be lost (McMinn 1991). The reasons for this concern are many, but one of the primary reasons that so many species are in trouble is that much of their habitat has been lost, and what remains is being badly fragmented (Chadwick n.d.).

In any given area, the variety of life and its processes are constantly changing, with or without the presence of humans. Thus, the concern is not with change itself, but with the effects of human actions on the nature and rate of those changes (Salwasser 1990). Ultimately, the concern is how those impacts and changes relate to global health and functioning - a relationship we are only beginning to understand.

Biodiversity is not about maximizing or managing for local diversity of flora or fauna, or species diversity in forest stands or communities, although the term is frequently used (erroneously) in this sense (McMinn 1991). Rather, the term encompasses the full spectrum of the diversity of life, including genetic, species, and ecosystem diversity and processes. As Chadwick (n.d.) states: "An ecosystem is not a collection of plants and animals. It is a seamless swirl of communities and processes."

As defined, biological diversity is so complex and intangible that its conservation cannot be approached without focusing on specific elements and processes (Salwasser 1990). Thus, in setting goals for biodiversity, specific achievable objectives for the principal elements of concern in an area must be established. This necessitates choices on which aspects of biodiversity will receive the highest priority. Several of these aspects are discussed below.

Since biodiversity is a global issue, a first step should be to assess how applicable the issue is in a particular management area. Much of the concern and most of the attention in the emerging field of Conservation Biology, the discipline most active in biodiversity issues, has centered on parts of the world where rapid or extensive habitat alterations are occurring; e.g., clearing and burning of tropical rainforests, or forest fragmentation in mid-western agricultural regions of the United States. In these areas, large-scale impacts on species, habitats, and even global climate patterns have necessitated immediate attention and action. Placed in this context, the changes in land holdings brought about by forest management activities may seem insignificant. However, there are reasons why biodiversity concerns should extend to all levels of land management operations.

First, forest management practices can have significant effects on the structure, species composition and function of plant and animal communities; while some species may increase or be unaffected, others may decline or even disappear on intensively managed areas (The Wildlife Society 1990). Such local extirpations can have broad implications, since the loss of even a single population reduces the planet's genetic diversity to some degree (Hunter 1990). Conversely, in some situations, species may require vegetation management to maintain their habitats (e.g. some fire dependent or early successional species). In such cases, forest management activities may not only be beneficial, but even necessary for the survival of those species.

Second, events on a particular land holding can take on added significance when viewed at a regional or landscape scale. If intensive residential development, forest fragmentation, or other habitat changes are occurring on adjacent lands, the value of an undeveloped land holding in the midst of that activity increases. Conversely, diversity can be affected through the general aging of the forest within a region, or the loss of large open areas as agricultural lands are abandoned.

Various authors have suggested strategies for conserving biological diversity, and most include consideration of some or all of the following components (proposed by Blockstein 1990):

- Research or Inventory - to develop appropriate strategies and set priorities, it's necessary to know the status of biological diversity in the management area;

- Protected areas - whenever possible, both "habitats of special concern" and representative habitats" should be set aside;

- Semi-natural areas - more attention must be given to opportunities for biodiversity conservation on lands that are affected by humans but still have significant natural elements;

- Endangered Species protection.

Despite their importance as a foundation for biodiversity conservation decisions and priority setting, basic biological research and inventories are often lacking in management programs. This is probably because utilitarianism has been the driving force in conservation over the last century; only recently has the intrinsic value of biodiversity and its value to global health gained recognition (Western 1991). Burley (1988) proposes a "gap analysis" approach to biodiversity conservation in which:

- the various elements of biological diversity in a particular region are identified and classified;
- existing and proposed systems of protected areas that help conserve biodiversity in the area are examined;
- poorly or under-represented "elements" (e.g., species, habitats, ecosystems, etc.) in the existing system of conservation areas are identified; and
- priorities for the next set of conservation actions are established.

Since some issues "count" more than others in a given situation, management decisions must focus on the most important (Thomas and Salwasser 1989); the need for good inventory data is apparent.

Species inventory is surely important, but the ultimate goal of biodiversity conservation programs should be to maintain the integrity of representative biotic systems (Western 1991). Various authors have proposed a coordinated, inter-agency approach to biodiversity conservation in which representative habitats, communities, and successional stages are maintained (e.g., Hunter 1990; Noss 1987; Franklin 1988). Such an approach can provide for a diverse array of protected communities on a regional, national, or even global basis, depending upon the extent of inter-agency coordination. Thus, an individual park or reserve might protect or manage for the habitat(s) the area is best suited for, and that best complement those on adjacent or other lands (Agee and Johnson 1988). A similar approach is already being practiced in several federal land management agencies that control multiple land holdings in different parts of the country (Agee and Johnson 1988).

The representative habitat approach usually involves the designation of certain areas as "set-asides" - i.e., areas where there is "no action, no matter what" - and these areas are important both in helping maintain biological diversity and as baselines from which the effects of human actions can be measured (Botkin 1990). However, such areas may not assure the conservation of all species or habitats of interest. Sometimes, areas must be actively managed to conserve specific biodiversity components. For example, the Kirtland's warbler may require active fire management (including setting fires) to maintain viable population levels (Botkin 1990).

Thomas and Salwasser (1989) have suggested that the arena in which the goal of conserving significant biodiversity in the United States will be gained or lost is in publicly-owned multiple-use lands; the "semi-natural areas" in Blockstein's approach described above. This necessitates that biodiversity conservation become one of the explicit goals of multiple-use management on these lands, and that appropriate management approaches be developed to ensure that biodiversity is retained while the lands continue to produce goods and services for people (Thomas and Salwasser 1989).

The strategy of protecting or managing for specific or representative habitats has widespread appeal among conservation biologists. Indeed, The Nature Conservancy estimates that a representative array of ecosystems will contain up to 90% of the species in a region (Hunter 1990). However, the problem with this approach (sometimes referred to as the "coarse-filter" approach) is that some species are almost certain to "pass through the pores" of the filter, because no habitat or ecosystem classification scheme is comprehensive enough to account for every species (Hunter 1990). Thus, a "fine-filter" component, which directs attention to individual species or habitats of special concern, is sometimes added to this approach.

Much of the focus of biodiversity research and programs has been on Rare, Endangered, or Threatened Species or Habitats, since they are in the most immediate danger of becoming extinct, thereby contributing to the decline in global biodiversity. This is an appropriate approach, and effective biodiversity programs must include threatened and endangered species conservation as a first priority (McMinn 1991).

Another idea relevant to biodiversity management is the "keystone species" concept. A keystone species is one that plays a role (as predator, prey, competitor, etc.) of much greater ecological importance than might be expected from its abundance or biomass alone. The stability of ecosystems may be very sensitive to the presence of these species, and their extinction or local extirpation can precipitate a cascade of extinctions in other ecologically-linked life forms (Frankel and Soule 1981). Management programs should include consideration of these species, since their loss from an ecosystem can have far-reaching disruptive effects.

2. Impacts upon Forest Fragmentation and Forest Interior and Early Successional Species Given Various Management Systems

In the eastern U.S., forest fragmentation has become one of the most important and controversial topics in wildlife management - important because the long-term viability of many species may be at stake, and controversial because the deliberate fragmentation of large contiguous forest patches is a time-honored practice of wildlife management (Wilcove

1989). Fragmentation occurs when large expanses of habitat are transformed into a number of smaller patches that are isolated from each other by a matrix of dissimilar habitat (Wilcove et al. 1986). For the most part, concerns regarding forest fragmentation have focused on the mid-Atlantic or mid-west regions of the country, where habitat fragmentation resulting from residential/industrial development (mid-Atlantic) or intensive agriculture (mid-west) has been dramatic. Fragmentation does not appear to be as serious an issue in the northeast (see DeGraaf and Healy 1989), where forest cover in many parts of the region is much more extensive today than it was a century ago. In Massachusetts for example, 29% of the state was in forestland in 1893, compared to 64% in 1985 (Petersen, n.d.). However, some of the specific impacts of forest fragmentation on wildlife (e.g., edge avoidance, increased nest predation) may be of concern even in regions where forest cover dominates the landscape, and these potential impasts must be considered in management planning.

Concerns related to forest fragmentation have grown out of theories concerning "island biogeography," which state that islands tend to have fewer species than nearby mainlands, and that small islands have fewer species than large islands (MacArthur and Wilson 1967). Later, these theories were applied to isolated "islands" of forests or other habitats, and the role of forest management practices in fragmenting habitats (see for example Harris 1984). Although there are some important differences between true islands and forest fragments, a flurry of research projects during the past two decades has produced enough similarities and reasons for concern that "forest fragmentation" is now a well-entrenched term in forestry and wildlife management disciplines.

Various mechanisms by which fragmentation causes changes in wildlife populations have been identified. Large expanses of unsuitable habitat separating forest fragments may serve as "dispersal barriers" for some species, preventing them from finding or reaching suitable habitat (Whitcomb et al. 1981). Small forest tracts may also lack the microhabitat conditions that existed in the original tract, and that some species may require (Wilcove 1989). For some species (e.g., large carnivores), forest fragments may simply be too small to constitute a complete home range or territory. Further, there is some evidence that certain forest songbirds exhibit a type of loose coloniality during breeding periods, and thus require forest tracts large enough to support a colony, not just a pair of birds (Hunter 1990). Small populations are also subject to problems related to demographic fluctuations, genetic deterioration and environmental deterioration (Soule 1987). Finally, a number of studies have demonstrated deleterious effects of "edges" on forest interior species (both plant and animal). These involve increased nest predation and parasitism (e.g., Wilcove 1985 ; Whitcomb et al. 1981), especially along forest edges, but possibly extending well into the forest tracts (Brittingham and Temple 1983), as well as changes in microclimate and seed sources (Ranney et al. 1981).

Most of the research on the effects of forest fragmentation on wildlife has been conducted on songbirds, although some work has also been done on mammals, amphibians and plants (Wilcove 1989). The songbird studies have generally found that long-distance migrants seem especially sensitive to fragmentation. Many of these species are also affected by the loss of tropical rainforests, which serve as wintering grounds. Since such species face habitat destruction and alteration on both ends of their migration routes, they are receiving a considerable amount of attention from conservationists.

This situation points to the need for a broad regional perspective when dealing with forest fragmentation issues (Hunter 1990). In the East, public lands are especially important since they include relatively large, undeveloped tracts. As such, they are important population reservoirs for wildlife sensitive to habitat fragmentation (Wilcove 1989). In Massachusetts, public lands account for only 16% of all forestland in the state, and the 84% privately-owned forestland is in relatively small parcels (Petersen, n.d.). Further, the Massachusetts Audubon Society predicts that by the year 2030, over two million acres (approx. 40% of the total land area) will be developed in Massachusetts (Leahy 1988). This situation suggests that forest fragmentation may become more and more important in the next few decades in Massachusetts, and that undeveloped publicly-owned land will take on added significance.

3. Wildlife Corridors and MDC Holdings

Corridors are usually thought of as strips of habitat that physically link, and thus allow species to move between, larger habitat areas. Corridors are often discussed in conjunction with forest fragmentation issues since, in theory at least, the problems associated with fragmentation might be mitigated by stringing habitat patches together with corridors (Hunter 1990). Unfortunately, there is little data available on the actual use of corridors, and while some researchers extol their virtues (e.g. Harris 1984), others question their value (e.g. Wilcove et al. 1986).

In all likelihood, the effectiveness of corridors depends on a number of factors including the type of organism concerned, its mode of movement, and the type and width of the corridor. Migratory birds may not require corridors, but for forest animals, a ribbon of trees wide enough to give them a sense of security surely facilitates their movement (Hunter 1990). Shelterbelts, hedgerows, and road or trail rights-of-way are common features of most landscapes, and undoubtedly expedite the travel of some species (Forman and Godron 1986). Even sedentary plant populations might expand along a corridor which provides adequate conditions to promote such "movement" (Hunter 1990).

As with most other aspects of habitat/wildlife relationships, the value of a landscape feature such as a corridor depends on the preferences or management goals of the landowner. For example, while corridors may allow birds to move freely among forest tracts, they may also act as funnels, attracting predators, competitors and brood parasites into those same tracts (Ambuel and Temple 1983). Likewise, transmission right-of-way corridors have been shown to have detrimental effects on forest interior birds (Bushman and Therres 1988).

Riparian zones are another form of "corridor" that have received a considerable amount of management attention. Harris (1984) considered riparian areas to be among the most productive of all habitat types in the western Cascades, and proposed a management strategy largely based on a system of variable-width "leave strips" along the streams and rivers in that region. There are many reasons why riparian zones support such rich wildlife communities. For one, riparian areas receive substantial water, nutrients and energy from surrounding uplands, and these not only allow for greater richness, but also impart more constancy to the occurrence of those resources (Harris 1984).

J. WILDLIFE IMPACTS ON WATER

Except for specific problem situations that have received direct attention (e.g., the role of beaver in *Giardia* outbreaks), relatively little formal research has been conducted on the relationships between wildlife and water quality. Thus, management policies regarding wildlife and water quality are often based upon presumptions of potential threats.

In general, the primary concern regarding wildlife and water quality is microbiological (e.g., bacteria, *Giardia*), although nutrient enrichment may also be an important consideration (Reinhert and Hroncich 1990). To date, wild animals are not known to be capable of transmitting pathogenic enteric viruses to humans (Leland and Berg 1988; Fed. Register 1987).

The main wildlife concerns on MDC watersheds relate to: disease transmission, indicator bacteria, general water quality parameters (e.g., turbidity, nutrients), and impacts on watershed cover. Each will be discussed here in more detail.

1. Diseases

Geldreich (1978) and Diesch (1970) provide good summaries of potential wildlife involvement in the transmission of water-borne diseases. These include Salmonellosis, Leptospirosis, Tularemia, Cholera, and others. However, in most present-day water supply systems, the actual risks posed by most of these are low. Most attention is given to potential contamination by *Giardia*, *Cryptosporidium*, and to a lesser degree, *Salmonella*.

Giardia is carried by a number of animal hosts (Davies and Hibler 1976) and has also been implicated in a number of water-borne disease outbreaks (Erlandsen and Bemrick, 1988). However, the actual role that animals have played in these outbreaks is not known. Most researchers believe that wild animals may be potential carriers of *Giardia*, but that human activity represents the original "source" of the contamination. Still, the U.S. EPA based many of the requirements of the recently promulgated Safe Drinking Water Act regulations on the presumption that all surface water supplies are susceptible to contamination from human or animal sources of *Giardia* (Fed. Register 1987).

Several *Giardia* studies have been conducted on Quabbin in recent years, in an attempt to understand the occurrence and distribution of the organism on the watershed (e.g. von Oettingen 1982; Speranza 1988). These studies have indicated that *Giardia* is present on Quabbin, but is not abundant.

Cryptosporidium has also received a substantial amount of attention recently, and a number of wild animals are known to be carriers of that organism (Rose 1988; Tzipori 1983). Waterborne outbreaks of both Giardiasis and Cryptosporidiosis have been documented in this country, and animal hosts may have been involved in these.

Concern has been expressed about wildlife involvement in the spread of Salmonella (e.g., Johnston et al. 1979; Monaghan et al. 1985; Jones et al. 1978), although no documented cases of waterborne outbreaks involving wildlife and reservoirs could be found in the literature.

2. Indicator Bacteria

Coliform bacteria are frequently used as indicators of possible contamination of water by other, more serious pathogens (Geldreich 1972). Thus, the role of wildlife in contributing coliform bacteria to water supplies is of concern. Various studies have documented elevated bacteria counts associated with animal populations, especially gulls (e.g. Benton et al. 1983; Gould and Fletcher 1978; Fennell et al. 1974) and waterfowl (Standridge et al. 1979; Hussong et al. 1979). Other species (e.g. deer and beaver) are suggested as potential contributors to bacterial loadings (Reinhert and Hroncich 1990; Malben and Foote 1955), but little actual documentation of such exists in the literature.

3. General Water Quality Parameters

Wildlife activity can impact water quality parameters in various ways. Nutrient loading, involving both nitrogen and phosphorous, has been associated with gulls (Portnoy 1990), geese (Norvell and Frink 1975) and other waterfowl (Brandvold et al. 1976). Beaver can have significant impacts on water quality parameters, including temperature, nutrient retention, organic matter decomposition, turbidity, and dissolved oxygen. They have also been implicated in several Giardiasis outbreaks. Due to the substantial influence of beaver on the Quabbin watershed, this topic is covered separately in Section J.5. of this Appendix.

4. Impacts on Watershed Cover

Several wildlife species are capable of altering the vegetative cover on the watershed enough to impact water quality conditions. Beaver influences are discussed later in the section. Deer influences on vegetation are also considered important enough to justify a deer population control program on the watershed. See section V. C. 3. a. of the Quabbin Land Management Plan for further discussion of this topic.

In summary, wildlife can potentially impact water quality in a number of ways, including disease introduction, bacterial and nutrient loading, impacts on miscellaneous water quality parameters and on watershed cover conditions. The greatest concerns involve those species that are capable of substantially altering habitat conditions (e.g., beaver and deer), those that can reach high population densities (e.g., gulls during winter months) and those that spend part or all of their lives in the water (e.g., waterfowl, beaver, muskrat).

5. Impacts of Beaver on Water and Watershed Conditions

No other native wildlife species is capable of impacting aquatic and adjacent terrestrial ecosystems more than the beaver, thus they have been the subject of much observation and research. The changes that beaver cause in habitat structure and function are complex, and usually involve both benefits and drawbacks, depending upon the management goals of landowners and the specific site characteristics (e.g. hydrology, soils, vegetation). These impacts have been discussed and studied for many years, although until recently, much of this work has dealt with the impacts of beaver on other values or resources (e.g., flooding of roads or timber; creation of waterfowl habitat). More recently, research has begun to focus on quantifying beaver impacts on biological, chemical and dynamic aspects of aquatic systems.

From a watershed management perspective, the main interest in beaver flowages and wetlands in general is the impact these resources have on, and the role they play in, water quality protection. This section examines some specific aspects of beaver activity. However, a larger issue of concern to the MDC is determining the optimal cover types for riparian areas within the watershed. The general value of wetlands and the specific value of forested wetlands are summarized in the following:

> Wetlands maintain or improve environmental quality by purifying natural waters by removing nutrients, chemical and organic pollutants, and sediments...wetlands play a key role in such processes because of their location between land and water. Thus, they can intercept runoff from the land before it reaches the water and help filter nutrients, wastes and sediment from flooding waters (Tiner 1984, as cited in Griffin, n.d.).

Many of the above values are specifically found in forested wetlands. For example:

> Forested wetlands improve water quality through deposition of sediments, assimilation of nutrients and organic matter, degradation of pesticides, and storing heavy metals ...Wetlands associated with streams and floodplains (such as red maple swamps) typically provide flood storage, slow flood waters, reduce flood peaks and increase duration of flow...However, the effectiveness of different wetland types for providing a flood control function are not known. (Sather and Smith 1984 and Repport et al. 1979, as cited in Griffin n.d.).

In examining the benefits and detriments of beaver activities, MDC plans further study comparing the value of beaver flowages with alternative riparian situations, such as forested wetlands.

Central to any discussion of beaver impacts must be an understanding of the history of beaver in the region. Although this is discussed in Appendix I, it will be briefly summarized here.

Prior to European settlement, beaver were common throughout North America; Seton (1929) estimated the population at that time to be between 60 and 400 million individuals. In New England, nearly every lake, pond, river and brook may have been occupied by beaver (Rudemann and Schoonmaker 1938). Intensive trapping during the 17th and early 18th centuries resulted in complete extirpation of the species from Massachusetts by the late 1700's, and no beaver populations were recorded in the state until some fishermen discovered a small colony in West Stockbridge in 1928 (Shaw 1948). Since then, natural dispersal and trapping and transplanting programs have resulted in rapid recolonization of many parts of the state. Today, beaver are again common throughout much of their former range in the eastern U.S., although the present population represents only a small fraction of earlier numbers (Naiman et al. 1986).

The beaver's absence from the region for over 150 years resulted in substantial changes in many attributes of stream ecosystems long before modern limnological research began. Thus, current concepts regarding stream ecosystems in North America were developed during a period which lacked the contemporary influence of beaver. Because of this, and recognizing that beaver constitute a "keystone species" in shaping stream ecosystems and surrounding landscapes (Webster 1983), a number of researchers have since called for a reassessment of those concepts (e.g. Smith et al. 1991; Naiman et al. 1988; Naiman and Melillo 1984). Consequently, the beaver-caused changes presently occurring in the drainage networks of MDC watersheds are, to some degree, a re-establishment of the prior conditions of many of those drainages, centuries ago.

Beaver impact stream ecosystems in ways that are diverse, far-reaching, and long-lasting (Naiman and Melillo 1984). Beaver activity alters wetland and riparian areas, modifies nutrient cycling and decomposition dynamics, alters sediment and organic matter transfer in the stream channel, modifies the structure and dynamics of the riparian zone, influences the character of water and other materials carried downstream, and influences plant and animal community composition and diversity (Naiman et al. 1988). Since unexploited beaver populations can influence 20-40% of the total length of 2nd to 5th order streams (Naiman et al. 1986), these impacts can represent significant alterations to local landscapes.

Characteristically, beaver activity may effect hydrology, erosion and sedimentation, water chemistry, physical parameters, ecology, and ecosystem function, as well as possible socioeconomic factors (e.g., recreation, irrigation). Each of these categories will be discussed separately.

a. Hydrology

Because the Quabbin Reservoir flooded the lower elevations of the Swift River Valley, beaver activity at Quabbin is focused on the upper parts of the original watershed, consisting of lower order streams.

Through the construction of dams and canals, beaver activity increases the extent of wetted surface area along drainages, sometimes as much as several hundred-fold (Naiman et al. 1986). This in turn changes the annual stream discharge regime, as current velocities decrease (Apple, no date; Naiman et al. 1988) and the volume of water in the drainage increases (Webster 1983). This results in elevated water tables (Wilde et al. 1950; Apple n.d.; Hill 1982) that can help to mitigate periods of drought (Webster 1983; Hill 1982).

However, the increased ponding of water in the drainage can also result in increased water loss through evaporation (Eschner and Satterlund 1965).

Beaver flowages can reduce the flood storage capacity of drainages, but beaver dams are often effective in reducing the power of floods also (Roth 1989). In certain mountainous regions of North America, beaver have actually been introduced as a means of alleviating flooding in lower-lying areas (Marcuzzi 1986). However, localized flooding of roads, fields and woodlands is often associated with beaver activity.

b. Erosion and Sedimentation

As streamflow is slowed by beaver dams, streambank erosion can be reduced and substantial amounts of sediment retained behind the dams. In Wyoming, a 90% decline in silt load occurred in one stream following the construction of a beaver dam (Brayton 1984). Naiman et al. (1986) found that even relatively small dams were able to retain as much as 6500 m^3 of sediment, and that a significant relationship existed between the surface area of a beaver meadow or pond and the amount of sediment retained. On a landscape level, Naiman et al. (1986) estimated that beaver might have been directly responsible for the retention of over 3 million m^3 of sediment on the 673 km^2 watershed they studied.

The potential usefulness of beaver in mitigating the impacts of erosion and downstream sedimentation has not gone unnoticed. Apple (n.d.) was successful in reducing erosion and thereby re-establishing and stabilizing riparian zones in several Wyoming streams by introducing beaver. It has also been suggested that beaver could be used to counteract erosional perturbations as part of large-scale management strategies.

MDC's experience with beaver dams includes both positive and negative impacts. For example, unstable beaver dams in certain locations wash out regularly in large storm events, releasing sediments, debris and organic matter downstream. In more stable locations, however, beaver dams have remained intact for many years. In these situations, substantial amounts of sediment accumulate in the pond, and over time, are stabilized by the growth of emergent and other wetland plants.

c. Water Chemistry

The changes in hydrology and sediment accumulation discussed above result in various changes in the chemistry of the water in beaver-influenced drainages. These include changes in concentrations, cycling and processing of carbon, nitrogen, oxygen, and metals, as well as changes in pH. Smith et al. (1991) studied water and sediment chemistry in an Adirondack Mountain stream system impacted by beaver. Their results indicated that beaver dams modify the chemistry of stream ecosystems both longitudinally and temporally, and also ameliorate stream acidity. Following transport through a beaver impoundment, stream water showed elevated levels of iron, manganese, dissolved organic carbon, pH and acid neutralizing capacity, and decreased levels of aluminum and SO_4. Dissolved oxygen concentrations were also decreased in the impoundment, but fairly rapid re-oxygenation occurred below the dam so that prolonged longitudinal oxygen deprivation was not evident. Beaver activity also played an important role in mitigating stream acidity; this appeared to be accomplished through the retention of SO_4 in the impoundment, and the enrichment of reducible metals.

Naiman and Melillo (1984) found substantial changes in the nitrogen budget of a stream altered by beaver, with the beaver-modified section accumulating approximately 1000 times more nitrogen in sediments than an unaltered stream segment. Much of this nitrogen remained sequestered in the sediments until the site was abandoned, at which time it was released to higher trophic levels.

d. Physical Parameters

Several studies of large impoundments (e.g. Baxter 1977) have shown various changes in the physical characteristics of the water following dam construction. These include decreased downstream turbidity and increases in temperature range (Malben and Foote 1955; Naiman et al. 1986). Wilen et al. (no date), studying water quality in beaver ponds on a small watershed in Pelham, Massachusetts, found an increase in water temperature at one of four study sites, but this was ameliorated by deeper water and shading downstream. Water color increased as a result of beaver activity however, and the detention and storage capacity of the impoundments extended the duration and the volume of colored water flow into the summer low-flow period. Still, Wilen et al. concluded that in reservoirs with sufficient capacity to dilute the highly colored water, no significant water quality problems would be likely to occur. Malben and Foote (1955) also found an increase in color resulting from beaver activity, and noted that increased water temperature, along with the growth of small animals and other life forms, could lead to odor problems; they also reported that debris from beaver activity may clog intake screens and valves, and increase chlorine demand in the water treatment process.

Hunt (1961) studied the effect of beaver activity on water quality in the Quabbin watershed during the early years of beaver occupation there. He found that the damming of large swamps caused increases in color, odor and taste of the water in and below the beaver flowages. However, he also reported that there was no detectable effect on the quality of water in the reservoir itself.

e. Ecology

Beaver activity can have dramatic effects on local ecology, both aquatic and terrestrial. Although some species of both plants and animals are adversely impacted (e.g., stream-side plant communities, certain cold-water salmonids), the overall ecological impact of beaver activity is enhanced biotic diversity of headwater streams (Naiman and Melillo 1984). In addition, the spot disturbances created by beaver result in increased landscape heterogeneity (Remillard et al. 1987) and vegetation flux that may increase habitat and species diversity (Forman and Godron 1986).

Beaver have both immediate and long-term effects on the biomass, structure and composition of riparian forests (Johnston and Naiman 1990). For example, through their selective feeding habits, beaver alter both plant species composition and the course of succession (Barnes and Dibble 1988). This impact is usually restricted to a relatively narrow band of forest surrounding the ponds, thus the effect is small on a landscape level, even though it may be large at the scale of the beaver pond (Johnston and Naiman 1990). Still, Naiman et al. (1988) found that a high-density beaver population in Quebec altered 12-18% of the forest. Johnston and Naiman (1990) found a 43% reduction in density and basal area of trembling aspen (*Populus tremuloides*) due to beaver foraging in northern Minnesota.

The flooding caused by beaver dam construction influences the local flora in several ways. The most obvious impact is the mortality of trees and other plants whose root systems cannot tolerate flooding. When combined with mortality due to tree-cutting by beaver, the resulting impact on timber resources can be substantial. Hill (1982) summarized recent estimates of beaver-caused timber damage in several southern states; these frequently amount to tens of millions of dollars yearly in some states. However, the resultant opening of the forest canopy also results in an increase in net primary productivity of existing subcanopy trees and shrubs, increased reproduction rates, and increased forest diversity (Johnston and Naiman 1990).

The elevated water table resulting from beaver pond creation results in increased growth in upland forests adjacent to the pond (Wilde et al. 1950). This growth may be further enhanced through the increased availability of nitrogen on the land surrounding the pond (Naiman et al. 1988). Wilde et al. (1950) found that chemical changes in areas submerged for more than 5 years resulted in the enrichment of the soils with ferrous iron, along with the fixation of phosphorous.

Faunal communities exhibit substantial changes following beaver pond creation. The main wildlife benefits derive from the presence of standing water, edge, and enhanced plant diversity, all in close proximity. The open water areas provide habitat for various birds, waterfowl, aquatic furbearers and fish, while the pond edges are attractive to regionally different assortments of rodents, lagomorphs, ungulates, predators, birds and other wild fauna (Hill 1982). Apple (n.d.) found significant increases in wildlife use of his study areas following beaver re-introduction. Rutherford (1950) conducted wildlife and vegetation sampling on two stream sections - one beaver-influenced and one not - and concluded that beaver exerted beneficial influences on both wildlife and fish populations. Reese and Hair (1976) found that beaver pond avifaunas were highly diverse during every season and that the widely recognized value of beaver ponds for waterfowl was minor compared to the high year-round use by non-game species. Dubuc et al. (1990) found that otter occurrence was positively correlated with the number of beaver flowages on Mt. Desert Island in Maine, due to the abundant food sources, stable water levels, abundant herbaceous cover, den and resting areas, and relatively low levels of human disturbance the beaver ponds provided.

Trout fisheries involving low-gradient or marginal trout streams can be adversely impacted as a result of beaver activity; such impacts include higher water temperatures, destruction of spawning areas and eggs by siltation, decreases in certain species of aquatic insects used as food, and inhibition of trout movement due to the barrier effect of dams. While these effects are most common in the eastern and north-central United States, in mountainous areas, beaver ponds are generally beneficial to trout fisheries (Hill 1982). Warm-water fish populations are generally enhanced by beaver activity.

The relationship between beaver activity and invertebrate populations is less well-studied, although the available data again suggest that some invertebrate species benefit while others are negatively impacted. In general, beaver ponds influence invertebrate community structure by replacing running-water taxa by pond taxa, and influence community function by increasing the absolute importance of collectors and predators, while decreasing the relative importance of shredders and scrapers in impounded sites (McDowell and Naiman 1986). Total density and biomass of invertebrates in beaver ponds may be 2-5 times greater than in stream sites (Naiman et al. 1988). The effects of the beaver pond also extend to downstream sites. Smith et al. (1991) found significantly lower invertebrate species richness and diversity, and collector-filterer, Plecoptera and Trichoptera densities, but significantly higher total invertebrates, Diptera, Ephemeroptera, predator, and collector-gatherer densities at sampling sites immediately downstream of a beaver impoundment. The authors attributed these differences to the influence of the beaver pond on stream acidity, iron concentrations, dissolved oxygen and benthic organic matter.

f. Ecosystem Function

The various impacts of beaver activity on the structure and composition of riparian zones described in the previous sections result in significant changes in the functioning of those ecosystems. Hodkinson (1975) found that a beaver pond is a highly accretive ecosystem, with only 18% of the total yearly energy input being exported, 26% respired, and 56% accumulated in the sediments. Likewise, large amounts of carbon (Smith et al. 1991), nitrogen (Naiman and Melillo 1984) and phosphorous (Wilde et al. 1950) are "captured" in beaver ponds. The net result of these actions is that substantial amounts of energy and nutrients are sequestered high up in watersheds, rather than being eroded downstream (Naiman and Melillo 1984). Large stable pools of biomass and nutrients with slow turnover rates serve to hasten recovery from certain types of disturbances (Naiman et al. 1988). Thus, beaver have a substantial influence on the stability, retention capacity and processing efficiency of drainage networks in North America (Naiman et al. 1986).

g. Other Impacts

Beaver impact water quality and watershed resources in several ways in addition to those discussed above. For example, beaver may be involved in outbreaks of waterborne diseases such as giardiasis (Craun 1984). Although they may not be the original source of the infection, beaver may serve as "amplification hosts" for the disease organism (Monzingo and Hibler 1987). However, *Giardia* cysts tend to settle quickly in still water, so infected beaver would need to be very close to a water intake for the water supply system to be at risk (Monzingo and Hibler 1987). Metzmaker and Rosquist (1986) considered beaver to be excellent sentry animals and the key to effective *Giardia* monitoring programs.

Hill (1982) lists various other benefits of beaver activity, including aesthetics, food and recreation benefits, aids in fire-fighting and irrigation, and a possible role in purification of acidic waters.

h. Summary

Whether beaver are considered an asset or a liability must be determined on a case-by-case and site-specific basis, depending largely on a landowner's objectives for managing a particular piece of land.

From a water supply standpoint, beaver activity may result in increased water temperature and color, higher bacteria counts, and increased risk of *Giardia* contamination. However, these impacts must be weighed against possible benefits associated with beaver in some locations such as increased sediment retention, nutrient sequestering, water table elevation and enhanced stream stability. Phosphorous retention in beaver ponds may be especially important in surface water supply systems, since phosphorous is often the limiting factor in the growth of algae and aquatic plants in reservoirs (Walker 1983).

From a water quality perspective, many of the impacts of beaver activity relate to the changes caused by the damming of water along stream drainages. Thus, the integrity of the beaver dam is an important factor in determining the longevity of those impacts. Dams that are prone to wash-out may cause water quality problems, since accumulated sediments that have not yet been stabilized by aquatic and emergent vegetation may be flushed downstream during wash-outs. However, Ives (1942) found that very shortly after deposition, sediments became firmly bound together by the root systems of plants growing in and around the pond, forming a matted zone of material that was surprisingly resistant to further erosion. Neff (1952) found that site stability after beaver abandonment was variable, but that most sites stabilized quickly and underwent little erosional damage in the subsequent 15 years.

Naiman et al. (1988) found that it was the dams on larger streams (i.e., above fourth order) that tended to be removed by freshets. On smaller order streams, the wetlands formed by beaver activity in their boreal forest study area appeared to persist in somewhat stable condition for centuries. Woo and Waddington (1990) also found that beaver dams remained relatively intact for long periods of time. They found that in most active beaver ponds, the dams were relatively impervious to water flow, and excessive water in the pond (e.g., due to storm events) was discharged over the top of the dam. When not maintained, the dams gradually lost their mud and finer debris, followed by the loss of stones and small twigs. The ability of the beaver pond to modulate the effects of storm events was thus related to the stage of decay of the dam, as well as the level of water in the pond prior to the event.

River otter also appear to play a role in the functioning of beaver dams. Reid et al. (1988) found that during winters months, otters often dug passages through beaver dams to insure under-ice access between adjacent water bodies. These passages served as slow release mechanisms, releasing excess water from the ponds. Most of these passages were repaired by the beaver during periods of open water.

The persistence of beaver-created impoundments and wetlands is also influenced by the nature of the underlying substrata and the resulting impact on drainage patterns. Wilde et al. (1950) found that following dam removal or site abandonment, beaver flowages drained only superficially, but not internally. This allows domination of the site by *Carex spp.* and other wetland plants, with a concomitant obstruction of natural forest regeneration. Naiman et al. (1988) reported that beaver activity influences the development of riparian soils through changes in litter quality returned to the soil.

Several researchers and managers have suggested or attempted reinforcement of beaver dams to add to their permanency. Wilde et al. (1950) felt that in some instances it may be advantageous to maintain beaver dams by inexpensive repairs after the colony has resettled elsewhere. Apple (n.d.) was successful in reinforcing and stabilizing washout-prone beaver dams using old tires or net wire.

K. RELEVANT INFORMATION FROM QUABBIN AREA RESEARCH

The MDC is fortunate that the Quabbin area has been the focus of several long-term hydrologic studies. These have included studies in the following basins: Cadwell Creek, Carter Brook, Mundberry Brook, Fever Brook, the West Branch of the Swift River, and Dickey Brook in Quabbin watershed; Natty Pond Brook and Bickford Pond watershed in the Ware River watershed; and Fort River in Shutesbury, adjacent to the Quabbin watershed (Batchelder et al. 1983; Hemond et al. 1987; Mader et al. 1972; Mrazik et al. 1980; Stekl 1985; Leonard et al. 1984; Rittmaster and Shanley 1990; Shanley pers. comm. 1993; Yuretich et al. 1986; Yuretich 1992). In addition, the Harvard Forest, on the Quabbin watershed, has been the site of a wealth of forest soils, vegetation, and ecosystem studies (Foster and Smith 1993; Lent and Smith 1994). In sum, these studies provide an excellent base of knowledge of the hydrology of several basins, the workings of wetlands within five basins (Natty Pond Brook, the East Branch of Fever Brook, Carter Brook, Mundberry Brook, and Bickford Pond watershed), the impact of limited cutting upon water yield on two basins (Cadwell Creek and Dickey Brook), and a preliminary understanding of the impact of air pollution and disturbance on the watershed (various Harvard Forest studies, Ottenheimer 1992, as well as all above basin studies). MDC has issued reports summarizing reservoir and tributary water sampling including a one year study of nutrients and metals (Austin et al. 1992; Austin et al. 1990 and Hartman et al. 1992).

1. Hydrology

In general, the hydrology (the variation in the storage and movement of water) within a given basin is the most critical factor in determining tributary water chemistry. However, the permeability and composition of the surficial deposits and bedrock represents a key underlying basis for hydrological differences (Yuretich 1992). For example, Reid (1992, pers. comm.) has studied one small stream within the Dickey Brook basin where variability of pH and alkalinity appear to be linked directly to variability in bedrock material.

A key hydrologic factor in determining stream chemistry is the amount of flow derived from groundwater versus subsurface flow, with higher inputs of groundwater causing increased acid neutralization (Yuretich et al. 1986). This is due to the close contact between subsurface materials and water and the slow movement of groundwater through basins. For example, Carter and Mundberry Brooks have groundwater residence times of 1-1.5 years (Yuretich et al. 1986; Leonard et al. (1984). found that groundwater residence time in Cadwell Creek varied from .3-5.2 years. Areas with high groundwater tables (generally more common in till than in stratified drift), high groundwater velocities and steep hydraulic gradients will buffer water less (Yuretich 1992; Leonard et al. 1984). Stratified drift deposits are invariably quite thick and can hold large volumes of groundwater, which ultimately serve to buffer both discharge fluctuations and chemical variability of the streams. (Yuretich et al. 1986; Batchelder et al. 1983). The contribution of groundwater to streamflow ranged from 37% to 75% at the various basins studied at Quabbin (Shanley 1993, pers. comm.; Rittmaster and Shanley 1990; Steckl, 1985). The general finding, that depth and type of surficial deposits and resulting contributions of storm flow and groundwater flow are a key factor in acid neutralization, is in concurrence with a comparison of two Adirondack basins by Peters and Murdoch (1985).

Yuretich et al. (1986) noted that the acid buffering potential for various streams can be estimated by mapping stratified drift deposits. Leonard et al. (1984) recommend dividing watersheds into hydrogeologic regions with predictable differences in groundwater chemistries as a way to estimate the overall impact of hydrogeology on water chemistry. For example, Cadwell Creek had lower pH and alkalinity than two other Quabbin basins studied, because it was more influenced by variable source input (stormflow) than groundwater flow. Mundberry Brook has a minimal susceptibility to acidification due to high groundwater influences. Yuretich (1992) concluded that Mundberry Brook represented the conditions found in most of the northern and eastern Quabbin drainages whereas Cadwell Creek was representative of many of the western Quabbin drainages. However, he felt that groundwater flowing directly into the Reservoir on the western side would reduce streamflow influences. An estimate of this groundwater flow would be important in modeling the Quabbin watershed. A first estimate could be achieved from data at hand, with a more accurate estimate requiring additional field study (Yuretich 1994 pers. comm.).

Rittmaster and Shanley (1990) studied two tributaries to the north and northeast of Quabbin Reservoir and found that the sulfate ion (rather than the bicarbonate ion) dominated the transport of base cations, indicating the initial signs of acidification. These basins still retain most of the hydrogen and nitrate ion input, although higher releases of aluminum and nitrate during storm events and snowmelt periods did occur possibly indicating initial stages of acidification. This study is unique because it represents a 21 month period when both regular and storm sampling occurred at specific sites.

The basin studies reported that nearly all precipitation infiltrates the soil and becomes part of subsurface or groundwater (and not overland) flow. However, at Cadwell Creek large amounts of water were measured flowing through the "O" horizon of the soil just below the surface (Yuretich 1992).

The timing of runoff after storms (i.e. the "flashiness" of streams) at Carter and Mundberry Brooks depends on the distribution and thickness of surficial deposits (Stekl 1985). Generally, thick unconsolidated surficial deposits increase baseflow contributions, groundwater residence time and specific conductance (dissolved ion concentration) of the water.

2. Water Quality

The MDC conducts regular water testing for a limited number of parameters at the Quabbin Reservoir and selected tributaries, as well as special monitoring projects as time and funding allow. In general, water quality at both the Reservoir and tributaries is high. Nitrate levels were low (.2-.4 ppm) in 13 regularly-monitored tributaries during 1989-90, but these measurements do not include storm events. A 4.5 year study of Dickey Brook concluded that nitrates in water were only a small fraction of the input from precipitation, and that biological uptake was the key factor in controlling releases (Shanley, pers. comm., 1993). A 21 month study at Fever Brook and the West Branch of the Swift River concluded that these basins retained the hydrogen ion at cation exchange sites and the nitrate ion by biota, but noted the occurrence of short-lived increases in the concentrations of these ions after large hydrologic inputs such as storms or rapid snowmelt (Rittmaster and Shanley 1990). Episodic releases of aluminum during large hydrologic inputs also occurred. Studies outside Quabbin also conclude that a high percentage of sediment and phosphorus leaves watersheds in just a few large storms (Meyer and Likens 1979).

Turbidity at Quabbin tributaries is generally low, with average 1990 readings on 8 tributaries and 2 reservoir samples of 0.2 - 0.7 NTU; the drinking water standard is 1.0 NTU. Dissolved oxygen is very high, averaging 82-100% saturated in 1990. Alkalinity at the reservoir decreased from 6.1 in 1950 to 3.1 in 1984, and rose to 4.3 in 1992. MDC water quality reports note that the low buffering capacity at Quabbin may be a potential problem as low pH levels can increase available metals (Austin et al. 1990; Austin et al. 1992). Although pH has remained fairly steady during this time period (6.4 - 6.8), there is concern that pH will begin to rapidly decline once buffering is reduced to very low levels.

Another parameter of concern for MDC is fecal coliform bacteria, the levels of which must meet strict standards. Average fecal coliform was within the source water standard of 20 CFU/100 ml for 21 of 23 Quabbin tributary sampling sites during 1990 (Austin et al. 1990). The authors note that fecal coliform tends to increase with increased precipitation and that more storm event water sampling should be conducted in the future. Two hurricanes which passed through Quabbin in 1991 caused increased fecal bacteria levels in 1991 due to the flushing effect of high storm flows (Austin et al. 1992). Sea gull activity near the Chicopee Valley Aqueduct (CVA) is of special concern. Gull harassment activities conducted by MDC in 1992 reduced fecal bacteria counts at the CVA for 1992.

From 1985 to 1990, the U.S. Geological Survey conducted a paired watershed study of two headwater basins of Dickey Brook on Prescott Peninsula. A 770 acre experimental and a 700 acre control basin were studied. The study concluded that H^+ and NO_3^- were mostly retained in the basins. Sulfate inputs exceeded outputs, with retention occurring in the wetlands and/or soils. Sulfate reduction in wetlands may be a key factor in the effective neutralization of acid precipitation which occurs at Dickey Brook (Shanley, 1993, pers. comm.). Yuretich (1994 pers. comm.) also reported that the Carter-Mundberry basin at Quabbin had significant alkalinity generation which was attributed to wetland processes. The importance of biological cycling is seen in the seasonal fluctuations of H^+, K^+, alkalinity, SO_4^-, NO_3^-, Cl^- and silica. However, discharge was the most important factor controlling the concentration of various components.

Hemond and Eshleman (1984) studied the Bickford Pond watershed in the Ware River basin and found that nitrate was being nearly completely retained throughout the year, even though atmospheric deposition was only 16% less than basins studied in the Adirondack Mountains where significant acidification and episodic nitrate and aluminum leaching has been measured (see Schofield et al. 1985). Nitrate retention was the source of 20% of the basin's alkalinity and the authors noted this figure may actually be considerably larger. The authors also suggest that extensive wetlands in the Bickford Pond basin may contribute to nitrate removals. McAvoy (1989) monitored two storms in the Bickford Pond basin. He found elevated aluminum concentrations associated with reductions in base cations for upland stream reaches and with organic acids for wetland reaches, making upland reaches toxic to fish due to the inorganic aluminum form. Elevated dissolved organic carbon and aluminum in upland reaches were attributed to rapid subsurface flow to streams because the soil infiltration capacity was exceeded in the B horizon.

The U.S. Geological Survey study of Dickey Brook offers the only focused study on the impacts of field creations and forest management on water quality at Quabbin. After one and one half years of monitoring the two basins, a pine plantation in the experimental basin was cleared and replaced with grass cover. Part of the hardwood forest in the basin was also cut, with a total of eight percent of the basin opened in these two operations. After the cutting and the harrowing of tree stumps to create the field, solute fluxes increased slightly, attributed primarily to an increase in water flux. Elevated suspended sediment concentrations were observed in a limited number of samples from the stream adjacent to the field clearing.

Hemond et al. (1987) modified the BROOK small stream hydrologic model (a U.S. Forest Service model developed at Hubbard Brook, see Miller et al. 1986) in order to undertake chemical modeling for the Bickford Pond watershed at Ware River. The authors chose BROOK because it is based on the "variable source" concept, and modified it to include additional wetland and groundwater storage components. The authors showed that upland water residence time, which is related to soil depth, can accurately predict water alkalinity.

3. Water Yields

Yuretich et al. (1986) found a close similarity between Cadwell Creek and Carter and Mundberry Brooks with regard to the percentage of precipitation that translates to stream runoff (runoff varied from 53-55% of precipitation). A vegetation management experiment was conducted on the upper 400 acres of the Cadwell Creek watershed from 1967-72 (Mrazik et al. 1980). Vegetation removal included deadening of trees in the riparian zone, thinning of plantations and partial harvesting of native forests, and totaled approximately one third of the basal area of the basin. These removals resulted in annual water yield increases of 22, 22, and 20 percent in the first three years after treatment. Approximately one half of the yield increases occurred during the growing season. The authors felt that the results of riparian cutting support the "variable source" model of small stream hydrology (Hewlett and Nutter 1970), and concluded that measurable water yield increases can be obtained without removal of large areas of watershed forest, by focusing cutting on areas where yield increases will be maximized. To obtain maximum yield increases with the least amount of cutting, they recommend removing all vegetation in riparian areas or areas with continuously saturated soils and implementing low density management in upland areas.

The U.S.G.S. Dickey Brook study (see #2 above) found that flows increased in the experimental basin by 3.5 inches for the first water year after cutting. Flows increased especially during the spring runoff and summer low flow periods. The moderate increases and short duration of increases due to cutting (only one year) were likely due to revegetation, especially in the created field area (Shanley 1993, pers. comm.). Verry (1986) reports that cutting does not significantly increase water yields in forests with high water tables; such conditions are common in the experimental Dickey Brook basin.

4. Wetlands

The effects of wetlands upon water quality may depend upon the residence time in the wetland. At Natty Pond Brook in the Ware River watershed, Suurballe (1992) determined that the longer the residence time in a wetland, the greater the effect on water quality. At Natty Pond Brook, water had high dissolved oxygen and transparency and was low in nutrients as it entered a series of wetlands. Changes occurred primarily in shallow wetland reaches which decrease dissolved oxygen and increase humics, color and dissolved organic carbon (DOC). In the Natty Pond Brook study, the stream was divided into four "reaches" with the greatest changes to water chemistry occurring where water travel time - affected by basin morphology and slope - was greatest. DOC more than doubled and color increased six-fold through the one reach having a travel time 2 - 12 times longer than the travel time of the other three reaches. DOC was affected by levels of dissolved oxygen and wetland size. As a whole, the wetland system studied slightly increased streamwater concentrations of ammonium, nitrate, sulfate, aluminum and phosphorus. Dissolved oxygen was greatly decreased, and DOC, color, iron, and organic acids increased in streamwater. It is noted that, during the growing season, plant uptake reduces nutrient inputs.

Rittmaster and Shanley (1990) found higher DOC at Fever Brook versus the West Branch of the Swift River and attributed this to the wetlands occurring at Fever Brook. Higher DOC was also associated with lower aluminum and with organic aluminum which is less harmful to fish, versus inorganic aluminum which dominated the West Branch of the Swift River. Sulfate reduction in Fever Brook wetlands resulted in 50% less export of sulfate in this stream versus the West Branch. Following their study of Bickford Pond, Hemond et al. (1987) concluded that swamps effectively remove sulfates and nitrates and that nitrates are also effectively removed by upland vegetation. They concluded that, in terms of sulfate retention, the hydrology of a wetland is a more important factor than vegetation cover.

Shanley (1993, pers. comm.) found that wetlands in the Dickey Brook watershed, which presumably were perched on impermeable till, actually made the watershed behave in a more "flashy" manner by acting as a saturated contributory area. In this study, the experimental basin had a much higher percentage of wetlands than the control due to beaver flowage, but the wetlands provided little storage because of high water table conditions. The result was lower overall water yields in the experimental basin, apart from increases attributable to cutting. Rittmaster and Shanley (1990) studied the West

Branch of the Swift River (with few wetlands) and the East Branch of Fever Brook (with large areas in beaver flowage) and found that water yield during a wet year was lower at Fever Brook (59% versus 48% of precipitation) and attributed this difference to evaporation from the greater extent of surface water at Fever Brook. Reduced water yields in the Adirondacks were also partially associated with beaver activity in a study conducted by Eschner and Satterlund (1965).

Austin et al. (1990) analyzed the annual MDC water quality data for Quabbin and Ware River and reported the lowest Ph and alkalinity readings to be at 1000 Acre Swamp at Ware River (average pH for 1990 was 4.8). In general, Ware River water has lower pH and alkalinity and higher color than Quabbin. This could be due to the large acreage in swamps at the Ware River. The authors recommend further study to determine the overall effect of wetlands on the water quality of the Quabbin-Ware River system.

5. Air Pollution

Studies summarized in #1 and #2 above conducted by the University of Massachusetts Department of Geology and Geography and published by the Water Resources Research Center (see Yuretich 1992 for a summary) were designed to determine the susceptibility of selected Quabbin tributaries to acid precipitation. Their findings show that susceptibility varies by watershed, but that many Quabbin tributaries are less susceptible than was previously thought). Hemond et al. (1987) concluded that the impact of acid deposition is affected by precipitation and dry deposition content, weathering and biological activity. Biological activity increases alkalinity through removal of sulfates and nitrates from the water. The Dickey Brook study found that acid precipitation was effectively neutralized, with riparian wetlands playing a key role through sulfate reduction (Shanley, pers. comm., 1993).

Ongoing studies at Harvard Forest in Petersham are focusing on the impact of nitrogen saturation upon forest ecosystems (Foster and Smith 1993). This research examines the response of different forest types to various levels of nitrogen inputs. Certain plots exposed to low and high inputs of nitrogen are already exhibiting some of the characteristics of nitrogen saturated sites. Further results from these experiments will hopefully shed more light on the impact of this type of air pollution upon these forests.

6. Relevance to Forest Management

While the research conducted in the Quabbin region provides a wealth of information about the hydrogeological workings of basins with differing physical characteristics, only the studies at Dickey Brook and Cadwell Creek, and to some extent Bickford Pond and Natty Pond Brook, consider the influence of vegetation upon hydrology and water chemistry. The MDC water quality data indicates that, for whatever reason, the Quabbin watershed does produce high quality water. Certainly Quabbin's undeveloped nature is responsible for keeping the water quality from degrading, as has happened in other, developed watersheds. However, some combination of bedrock and surficial geology, topography or vegetative conditions also contribute to Quabbin's high water quality.

Studies at Cadwell Creek clearly show that a program of forest removal, concentrating on riparian areas, can measurably increase water yields. However, the Dickey Brook study shows that water yields will vary by site and forest management approach. The Dickey Brook study is the only long-term watershed study which specifically examined the effects of Quabbin land management activities upon water quality. This study generally found that solutes increase proportionately with water flow. The suspended sediments measured in a stream adjacent to a large field clearing and harrowing operation indicate that this practice does cause limited water quality impacts. However, no impacts were related to partial forest cuttings. The record of high water quality at Quabbin over the past 30 years (during which forest management occurred on more than 20,000 acres) also supports the lack of impact that Quabbin forest management has upon water quality parameters measured by MDC.

Research at Harvard Forest provides information on the impacts of land use over the past 350 years upon the make-up of the region's forests. Harvard Forest research in the areas of natural disturbance and air pollution will become more useful as the research progresses.

Research at Natty Pond Brook, Bickford Pond and Dickey Brook provides information regarding the impact of wetlands upon water chemistry. MDC data analysis reports recommend that further research be conducted on the impact of wetlands. A key element missing in the above research is an evaluation of wetland impact and function by wetland type and hydrologic location. Due the great prevalence of beaver flowage wetlands at Quabbin, more information on this type of wetland would be useful.

While the Quabbin region research does not provide a great deal of guidance in selecting a forest management approach, it will be useful as a foundation to future research and in guiding this research towards areas where more information will be most useful for management decision-making.

L. RELEVANT INFORMATION FROM PAST QUABBIN WATERSHED MANAGEMENT

The MDC lands at Quabbin have been actively managed for more than thirty years. This is the fourth management plan for the Quabbin lands, making this the most consistent forest management planning completed on any public lands in the state. Each plan had as a goal the development of a resilient forest which was suited to the various site conditions at Quabbin. Each plan called for an uneven-aged management approach, emphasizing long-lived species. Plans in the 1970's and 1980's added the goal of increasing water yields, in response to an increasing water demand and an extended period of drought).

Past forest management at Quabbin has included the completion of silvicultural operations on more than 20,000 acres in a wide variety of sites and forest types. The Quabbin foresters treat each forest operation as a "working hypothesis" and track the results, both formally and informally, for use in fine-tuning future silviculture. Staff meetings are utilized to share this knowledge so that foresters can accurately predict the results of an operation upon a given site and forest type at Quabbin. This knowledge is extremely important in evaluating management options.

1. Silviculture

As controlled deer hunts reduce deer impacts within the Reservation, the most useful model for the application of silviculture for watershed management is the MDC land where deer hunting has continuously occurred; this is the more than 7,500 acres outside the highways that surround the Reservoir. On these lands, the forest responds to silvicultural operations with little interference from deer browsing. Within this area, site characteristics and species composition are varied, and knowledge gained can be applied to future management of the 50,000 acres in the Quabbin Reservation. The most useful sites for this purpose are those which have been continuously managed for twenty years or more.

Areas outside of the highways have received uneven-aged silvicultural treatments ranging from single tree to group selection. Overstory loss due to gypsy moth and oak leaf tier on forests previously receiving "preparatory" regeneration cuts have approximated a "shelterwood" silvicultural approach. The response of regeneration varies by size and aspect of the opening, height of surrounding trees, and stocking and composition of the surrounding forest. In general, foresters have found that single tree removals encourage shade tolerant species, such as hemlock. A wide variety of species have regenerated well with openings of 1/10 - 1/4 acre. Sites surrounded by shorter trees regenerated well, especially where stocking was also reduced in the surrounding forest. On level sites, larger openings (approximately 1/4 acre) have allowed a diversity of regeneration (shade tolerant at edges and intolerant in the middle) to develop without interference from the adjacent forest. Southerly-facing aspects can get the same results with smaller openings, while larger openings will be necessary on northerly-facing slopes.

Preparatory cuts have been employed in the lands outside of the highways in an effort to increase the representation of long-lived, intermediate shade tolerant species in the regenerating forest and to increase the rapidity of response when openings are made. In general, preparatory cuts are more useful on mesic (moist) sites where fast-growing, shade-intolerant species such as black birch and black cherry will otherwise dominate the response to release cuts. With preparatory cuts, regeneration on these sites will be a mix of birch, cherry, maple, oak, pine and hemlock. Timing preparatory and release regeneration cuts to correspond with seed years for various species helps improve results. In the past, MDC policy has been to allow regeneration to develop past deer browse height (4.5') before removing overstory. However, overstory die-back from insects on large acreages with smaller, established regeneration has shown that this smaller regeneration can respond well and maintain a diversity of species in some cases.

At both Quabbin and Wachusett, the response of forests after tornadoes indicates that where forest management has created openings in forests prior to such disturbance, the response of regeneration is more rapid.

On areas where both deer browse levels and forest composition have been continually managed for 25 years, the diversity of sizes and species of trees is evident from each point in the forest. While very large trees can be viewed from anywhere in the forest, patches of regenerating forest and pole-size trees are also present.

2. Water Yields

While the Quabbin area research section summarizes studies at Cadwell Creek and Dickey Brook, general information from past management efforts aimed at increasing water yields is also useful. For example the management plan for the 1980's recommended replacing 3,000 acres of pine plantations with fields and reducing stocking on 23,000 acres in order to increase water yields. However, only 400 acres of pine plantations were cleared and stocking reduced on 11,450 acres. The reason that the plantation thinning program was implemented much more slowly than planned was due to the need to carefully supervise each operation because of the heavy equipment involved. The creation of small areas of "savannah" with 20-40% residual stocking (the plan recommended 2,800 acres) served to stimulate dense ferns in many areas with a likely limited increase in water yields and future challenges in gaining tree regeneration. With a stronger emphasis on water quality and with a reduced deer population, non-forest options for increasing water yield are less feasible. MDC foresters feel that future water yield enhancement programs should be limited to managing lands in varying ages of continuous forest cover in order to reduce program impacts and increase protective qualities of MDC lands. More site specific research is necessary to study the effects of an acceptable range of forest management approaches upon water yields on a range of basin types.

3. Best Management Practices

The development of specific best management practices for Quabbin (see Quabbin Watershed Land Management Plan Section V.B.2.) was primarily based on experience from past logging operations. During the 1980's, MDC formed a committee of foresters and timber harvesters to examine the issue of logging equipment restrictions. The result is a unique method of limiting logging equipment by ground pressure and overall width which is defined in MDC's timber contracts. While operator skill is critical to low impact logging, restrictions on equipment serve to further reduce impacts. By being specific and consistent regarding equipment restrictions, MDC has encouraged the private sector to purchase certain types of equipment (e.g. forwarders, feller-processors). The large increase in the number of timber lots restricted to forwarders has helped put MDC management in a class by itself with regard to low impact logging. The large number of private forwarders available is also a very important contingency in the event large scale salvage is necessary, as forwarders have proved especially important in low impact salvage operations.

By meeting stringent, high standards, timber harvesters have gained stable work on Quabbin timber lots. The MDC watershed management crew (hired in 1986) was originally meant to work on a wide variety of sensitive sites. However, the excellent response of the private sector has reduced the need of this crew in forestry operations and allowed the concentration on woods road restoration and maintenance and other watershed management projects including tree planting, cultural site protection and fire suppression. Crew members have also been invaluable in the training of private timber harvesters in safe, low impact logging techniques. Silviculture carried out by the crew includes the use of equipment which the private sector has in limited numbers (such as the feller-processor for operating in pine plantations) and the operation of sites which are not commercially feasible or where extraordinary care is necessary, as in the case of cultural site preservation.

4. Fire

Wildfires are potentially the greatest impact that humans have upon MDC lands.

Intense wildfires in the 1950's charred thousands of acres of lands on Prescott Peninsula and on the north side of Route 122. However, in the past three decades fire suppression efforts by MDC and local towns have greatly reduced fire impacts. The addition of the MDC watershed management crew has greatly increased MDC's ability to suppress fires. In the past ten years, the 12 wildfires which have started on MDC lands on the Quabbin watershed were controlled, so that only 60 acres were burned.

5. Forest Roads

MDC crews have made extensive progress in restoring the network of Quabbin roads into a well maintained condition. This has involved repairing ditches, installing culverts and detention basins, and re-establishing gravel road bases (see Quabbin Watershed Land Management Plan Section V.A.6.). This work has improved the State Police's ability to regularly patrol interior areas and has improved MDC's ability to gain access to the forest for water sampling, fire suppression, and forest salvage efforts. The system will be even more important in the event of a large disturbance. Road improvements also limit erosion and sedimentation associated with large storms. The gating of roads previously open to traffic has reduced the number of incidents of trash and debris dumping and has lessened road erosion resulting from use during wet conditions.

APPENDIX III. WATERSHED FOREST MANAGEMENT AND UNEVEN-AGED SILVICULTURE: A COMPARISON OF GOALS AND TECHNIQUES

Goals

The goal of watershed forest management on the Quabbin is the long-term protection of water quality through all types of disturbances and the buffering of atmospheric and water-borne pollutants. It has been determined that the forest which best provides this protection consists of a vigorous, multi-layered, dense cover composed of developing trees of all sizes/ages. This forest has a well-developed vertical structure which is capable of filtering and buffering pollutants and a continuous spread of ages and sizes so that recovery from disturbance can occur with minimal delay. Furthermore, this forest is most secure when composed of native species well-adapted to the sites on which they are managed.

David M. Smith (1986) makes the following statement about the goals of uneven-aged management while discussing the "ideal status" for balanced uneven-aged stands:

> One of the most attractive and idyllic concepts of forestry is that of the all-aged stand; it continually yields benefits and regenerates itself steadily; it is a dynamic system that is always the same and always in balance. It would be a perfect sustained-yield unit and would also approximate some state of ecological equilibrium, however that might be defined.
>
> Even though this condition has a powerful naturalistic appeal, it is not one that would come into existence in nature but would have to be an essentially artificial creation. One would have to regenerate the same amount of forest area each year for about a whole rotation to create the condition exactly. It is a simple encapsulation of good ideas toward which foresters strive by various means but should not expect to achieve perfectly.

Uneven-aged management can be a difficult regulatory system to implement, requiring short cutting cycles, frequent inventory, and constant tending of management areas. In a commercial setting, it has the appeal of providing a constant yield of mature timber from a balanced distribution of tree ages and sizes. The constant presence of large as well as small trees in the forest landscape also meets aesthetic goals and has wildlife benefits that even-aged silviculture may preclude.

In a watershed management context, a sustained yield of mature timber is incidental, while the balanced forest structure is of paramount importance. Both goals require steady recruitment of trees into the youngest age classes (i.e. regeneration) and removal (i.e. harvest) of individuals which have reached a pre-defined point of maturity or risk. Once this "end point" has been defined, the techniques for applying uneven-aged management in either watershed management or commercial forestry are similar.

Techniques

In commercial forestry, the definition of "maturity" is arrived at by working a desired rate of return against the growth potential of species on different sites. For example, red oak will meet a 6% (volume) rate of return on average sites (site index 60) until it is about 18" in diameter at breast height. Under these constraints, 18" dbh would be the largest red oak class managed. As site quality improves and required rate of return diminishes, individuals are grown to larger final diameters. Red maple grown on excellent sites will continue to return 2% until it reaches 32" dbh, for example.

In watershed management, rate of return is not directly related to water quality protection goals, but it does provide a measure of vigor. Arbitrarily setting a 2% (or higher) rate of return provides some assurance that even the oldest/largest trees maintained will be sufficiently vigorous to resist disease and decay. Trees unable to resist decay are risky components of the watershed forest. Over a broad range of species and site conditions, the 2% return dictates maximum dbh classes from 20 to 32". These limits in turn set the numbers of trees to be maintained in smaller size classes, as described below. It should be made clear, however, that there is little reason to harvest healthy, vigorous trees which exceed these "end point" diameters on the watershed. Setting end points merely guides the definition of the forest structure the manager will work to create.

To continuously replace the trees in the largest diameter class, uneven-aged management maintains a constantly decreasing number of trees from the smallest to the largest diameter classes. The quotient of the number of trees in any given diameter class over the number in the next larger class defines the "q", the critical constant in an uneven-aged prescription. This constant generally ranges from 1.2 to 2.0. In commercial forestry, where the goal is to keep a large percentage of the growing space allocated to large, valuable timber, the "q" must be maintained as low as practicable. This requires a great deal of tending of the lower size classes, which often is not possible until they reach the commercial threshold of 6-8" dbh. In the watershed context, vigor can be maintained at a higher "q", which reduces the need for non-commercial weeding and thinning of the smaller diameter classes. The chart below gives a simple example of the differences between an acre managed to a 24" dbh maximum under $q=1.3$ and $q=2.0$. Again, the lower value might be followed to maximize timber production, while the higher value would meet watershed management goals.

DBH Group	"q" = 1.3	"q" = 2.0
1-5"	81 trees/ac	406 trees/ac
6-10	42	111
11-16	25	21
17-24	13	3
ALL	161	541

In all forms of uneven-aged management, the regeneration system involves either single tree or group selection, aimed at steadily reducing the number of trees in the upper size classes and recruiting new trees into the smallest classes. Single tree selection and small group selection generally favor the regeneration of shade tolerant species (such as hemlock, beech, sugar maple), as the amount of new light reaching the understory is limited. To regenerate shade intolerant species (paper birch, hickory, poplar) or intermediates (oak, ash, red maple, black and yellow birch) the size of the groups selected for harvest needs to be larger, but generally no larger than 0.5-1.0 acre.

Uneven-aged management generally requires short cutting cycles to maintain recruitment and the desired age/size distribution, especially where high rates of return require shorter rotations. In most commercial applications, cutting cycles of 10-15 years are recommended. In watershed management, with a high "q", a low desired rate of return, and large diameter end points, both the rotation and the average cutting cycle are lengthened. Furthermore, watershed protection dictates that stands which are more exposed to risk, such as mature white pine on aspects historically susceptible to hurricane damage or oak on xeric hilltops, require more frequent attention than those less exposed to risk. Cutting cycles would be frequent on high risk areas, to culture a resilient balance of sizes and species, but tending of low-risk areas would be minimal.

The constant presence of trees of all sizes, as well as the greater frequency of entering stands, makes harvesting more problematic than under even-aged management. Some of this may be eliminated by emphasizing group selection, so that age classes are concentrated in small groups rather than evenly distributed throughout the forest. However, the protection of smaller size classes will place some limitations on harvesting systems, which increases costs associated with management. Where watershed protection has already dictated these harvesting limitations, they will not represent a new cost.

Changes in the Quabbin Forest Resulting from Uneven-aged Management

The recent success in reducing consumer demand for water in the metropolitan area, coupled with increasing threats to water quality, has shifted management emphasis away from water yield improvements and more strongly toward uncompromising, long-term water quality protection. This change in focus will shift forest management priorities and some of the details of silvicultural prescriptions.

Conifer species, because they maintain their needles throughout the year and continuously transpire water, use more water than deciduous species. Shifting watersheds from conifers to deciduous species results in increased water yield to reservoirs. Where water conservation efforts can compensate for losses from conifers, there is no need to reduce conifer presence on the watershed. Furthermore, because conifer needles continue to catch precipitation throughout the year, they may provide superior water quality protection over deciduous species. Studies have shown that conifers are superior as particulate sinks, although woody surfaces of both conifers and deciduous trees are significant sinks throughout the year (Carlton 1990). Deciduous trees may be superior in riparian areas, in particular, because they have greater nutrient demands than conifers; for example, oaks require more nitrogen and potassium than spruce or pine (Perkey et al. 1993).

Some species, notably hemlock and sugar maple, are extremely shade tolerant. Uneven-aged silviculture favors these shade tolerants, which fill in single tree and small group removals as well as the inner edges of larger group selections. Hemlock is also attractive in that it will grown on a very wide variety of sites, and will respond to release even after very long periods of suppression.

While uneven-aged management and the emphasis on water quality may favor conifers on some sites, local factors may sometimes favor deciduous species. Studies at the Harvard Forest following the hurricane of 1938 showed that conifer forests were susceptible to destruction by wind at age 30, while hardwood forests maintained some resistance to wind destruction until they reached 80 years. On moist, rich sites, the root structure of hardwoods such as sugar maple or beech are more wind resistant than those of most conifers. Individuals of any species grown in uneven-aged forest may develop some level of wind resistance simply through repeated exposure on open sides to non-destructive winds. The most critical long-term defense against deforestation by catastrophic wind damage is built into uneven-aged management at the stand level. In an uneven-aged stand, the younger/smaller trees already present in the understory may take immediate advantage of resources made available by the destruction of larger/taller trees.

At least two conditions in the Quabbin forest make it susceptible to problems associated with even-aged management: the overbrowsing by deer of the understory, and the preponderance of just two, older, age classes - 50 years and 80-100 years. Converting these older stands to uneven-aged management will either begin immediately or following the establishment of regeneration through preparatory cuttings and/or hybrid even-aged approaches. For instance, stands of large, mature white pine and oak with deficient understory conditions, growing on south, southeast and east aspects (which have historically been susceptible to damage from hurricane winds), may be more quickly regenerated through irregular shelterwood management. To the extent that it produces the desired multi-layered forest more efficiently than the selection methods, the irregular shelterwood method may be the preferred silvicultural treatment in these situations. The irregular shelterwood method differs from standard shelterwood practices in at least two ways:

a.) the overstory is removed more gradually, through the expansion of initial openings, so that the removal/replacement of the overstory takes considerably longer than 20% of the rotation (the convention for standard shelterwood, and

b.) the result of this protracted removal is that the stand contains two age classes (each technically "even-aged") for longer periods of time, and furthermore, that the younger age-class develops height variation which mimics uneven-aged structure (Smith 1986).

Uneven-aged Watershed Management - The Perpetual Forest

While the fully regulated, all-aged forest, with the desired number of trees in each diameter class evenly distributed throughout the watershed may be beyond reach, the concept of a perpetual forest everywhere must be the intention of watershed management. The performance measure for the success of this concept is sufficient distribution of tree ages, sizes, and species throughout the forest to prevent disturbance from causing even brief periods of unforested conditions. For example, southeast hillsides with even-aged mature pine and limited understory can be obliterated by strong winds and require several years to reestablish a new forest. If the same hillsides consisted of groups of trees of many different sizes, some of these groups would survive because they were immature, and would provide forested continuity beyond the disturbance. Similarly, encouraging a mix of pine and oak on upland oak sites provides forested continuity beyond a gypsy moth infestation. The absence of continuity leaves the disturbed areas susceptible to further damage, such as erosion of unvegetated land, or fire in large, contiguous windthrow. The retained patches of undisturbed trees within the "perpetual" forest greatly diminish the threat of this further damage.

The selection harvesting methods associated with uneven-aged management mimic the normal processes of senescence and death in unmanaged stands. However, they are applied regularly throughout the forest specifically to prevent stands in exposed areas from developing into even-sized, mature blocks, or to add variety where major disturbance has created homogeneity. The continuity of the even-aged forest is infrequently disrupted by large scale disturbances, from which it can eventually recover. The balanced, uneven-aged forest persists through these disturbances; this limitation of the overall impact of disturbance is clearly desirable for long-term continuous protection of water quality, and is the justification for building a continuous, perpetual forest through uneven-aged management on the watershed.

APPENDIX IV. LAND PROTECTION FOR WACHUSETT, QUABBIN, WARE RIVER AND SUDBURY WATERSHEDS

A. LAND ACQUISITION PLAN FOR THE DECADE

1. 1985-94 Land Acquisition Program Objectives and Accomplishments

a. Program History

Between the completion of the Quabbin Reservoir project (1938) and the mid 1980's, the MDC completed only sporadic land acquisitions, generally triggered by the potential development of an especially critical parcel. While development booms in the 1950's and 1960's impacted the Sudbury and Wachusett watersheds, these were not seen as critical by the agency staff. However, cases of lowered water quality due to land development have been documented; for example, turbidity increases significantly as development increases in Wachusett drainages. East Wachusett Brook is 89% undeveloped and had an annual average turbidity of 0.3 Turbidity Unit (TU), while Gates Brook which is only 52% undeveloped had an annual average turbidity of 1.2 TU (EPA drinking water standard is 1.0 TU). Other parameters, such as phosphorus, nitrates, and chlorides, also tend to increase with development (MDC 1988 Water Quality Report).

The passage of the 1986 Safe Drinking Water Act Amendment Regulations and the extensive building boom of the 1980's were the key driving forces behind the Watershed Protection Land Acquisition Program. Regulations which clearly and specifically linked land ownership and management to necessary water supply protection, together with an imminent threat of development on critical watershed lands, brought the need for the Acquisition Program into sharp focus.

The 1987 Open Space Bond initiated MDC's current land acquisition program with an allotment of 30 million dollars. In preparing the request for the bond law, MDC evaluated lands on the three active watersheds and estimated the acreage and money necessary for an effective land acquisition program (French 1988). This request outlined the need for the acquisition of 14,000 acres with an estimated expenditure of 41 million dollars. It was estimated that 8,800 acres of priority parcels could be purchased with 30 million dollars.

SDWA Amendment Regulations required MDC/MWRA to complete Watershed Protection Plans for Quabbin, Ware River, and Wachusett watersheds in 1991 (MDC/MWRA

1991). These plans were required in order to file for a waiver of the filtration requirement under the new regulations. As controlling or owning all watershed lands was one criterion for EPA's decisions on filtration plant waivers, land acquisition was a critical part of the plans. Therefore, MDC completed a more extensive evaluation of lands within the three active watersheds where acquisition was important for water supply protection. This evaluation recommended that 19,600 acres of lands in the three watersheds be purchased at an estimated cost of 61 million dollars.

The passage of the Watershed Protection Act (WPA; Chapter 36, Acts of 1992) included a land acquisition bond totalling 135 million dollars with a mandated spending rate of 8 million dollars per year. The MDC is currently completing a land parcel selection mapping model utilizing Geographic Information Systems (GIS) in order to prioritize the expenditure of the 135 million dollar bond. This model is based upon an updated set of parcel selection criteria.

None of the land acquisition bond issues outlined above included authorization for expenditures at the Sudbury watershed, as this is an emergency and not active water supply. In 1990, a committee including EOEA land holding agencies and local non-profit land protection organizations assembled a proposal for improved coordination of management of EOEA lands in the Sudbury region. This proposal included a request for land acquisition within the Sudbury watershed. To date, some of the priority parcels in the Crane Swamp and Cedar Swamp have been purchased by the Sudbury Valley Trustees. The MDC is currently examining the possibility of utilizing Chapter 275, Acts of 1989 (Section 7) which establishes a Watershed Preservation Restriction Program funded by a 20 million dollar bond.

b. Program Goals and Accomplishments

The 1987 Open Space Bond Issue (Section 3 of Chapter 564, Acts of 1987) established a 30 million dollar account under the Executive Office of Environmental Affairs to purchase property in the Quabbin, Ware, and Wachusett watersheds for "the protection of the water resources of the Commonwealth". The General Court delegated responsibility for expending these funds to the Metropolitan District Commission (MDC) and the Division of Fisheries and Wildlife (DFW).

In joint meetings between the MDC and the DFW, it was agreed that water supply protection was the first priority in the expenditure of these funds. Because DFW's chief mandates are wildlife protection and enhancement, lands which protected both water and wildlife would be chosen, where possible. Within the goal of protecting the water supply, the following criteria were used in prioritizing parcels for acquisition under the 1987 Open Space Bond Issue:

- Lands adjacent to major reservoirs and tributaries, especially those threatened by development,
- Lands in important tributary aquifers, especially those threatened by development,
- Lands in important tributary wetlands, not included above,
- Lands adjacent to MDC/DFW or other public lands within the watersheds,
- Lands that make management of existing MDC/DFW ownerships more efficient through improved access, reduction of boundaries, consolidation of parcels, and prevention of illegal access to MDC/DFW lands, and
- Lands valuable for wildlife habitat, scenic amenities, and open space.

The 1987 MDC Land Acquisition Plan listed a total of 14,102 acres estimated to cost $41,097,400. The plan estimated that 8,800 acres could be acquired with an allotment of $30,000,000.

Table 2 (below) summarizes planned versus actual spending for the fiscal years (FY) since the inception of this program. FY 94 represented the first full year when MDC had expended the 1987 bond and began spending the 135 million dollar Watershed Protection Act bond.

Table 2: **MDC/DFW Land Acquisition Spending for Wachusett, Ware River, and Quabbin watersheds, Fiscal Years 1985-1994**

FISCAL YEAR (July - June)	Planned Spending		Actual Spending	
	$(1000's)	ACRES	$(1000'S)[1]	ACRES
1985	3,000[2]	1,250	58	51
1986	2,942	1,200	0	0
1987	2,942	1,200	1,150	679
1988	15,000	575	471	98
1989	15,000	675	6,006	710
1990	15,000	4,850	7,028	2,119
1991	15,800	5,114	9,576	3,425
1992	10,909	4,427	4,349	941
1993	7,000	1,600	7,100	1,504
1994	8,000	1,800	8,100	1,896
TOTALS	33,000	9,500[3]	43,838	11,423

[1] includes MDC/DFW land ancillary costs

[2] reflects 3 million dollar 1983 bond issue, which was used to purchase 927 acres from FY 1985-89, and is included above in "Actual Spending" column

[3] Reflects overall plan to spend 33 million dollars allocated in FY 83 and FY87 bonds, and the acreage to be purchased with these monies

2. Land Acquisition Goals for 1995 and Beyond

a. Concept for Efficient Protection of the Water Resource

The MDC completed the expenditure of the 1987 bond issue during FY 93, and the implementation of the 1986 SDWA Amendment Regulations is now well underway. It is critical to assess the water supply protection effectiveness and cost effectiveness of further land acquisition. While dramatic conclusions can be drawn from examining developed drainages at Wachusett and Sudbury Reservoirs, the actual impacts of "build-out" scenarios of lands likely to be developed will not be known until after development has occurred. Modern hydrologic models show that lands in and around tributaries, aquifers and wetlands will contain the greatest proportion of a basin's water, at any given time. The "varying source" model which describes most small, undisturbed New England watersheds emphasizes the importance of low lying, water-rich areas in contributing the majority of runoff during storm events, through saturated subsurface and surface flow (Dunne and Leopold 1978; Hewlett and Nutter 1970). As a precipitation event continues, the area included in saturated flow increases. However, even in extended large events, the variable source is still less than the majority of the watershed, in most cases.

Studies show that pollutants added to the water-rich, "varying source" areas of small watersheds in New England have a proportionately larger impact upon tributaries (Dunne and Leopold 1978). Therefore, development focused on these water-rich areas will have a proportionately larger negative impact upon the water resource.

The logical conclusion of this discussion is that by focusing upon protecting variable source and aquifer areas, the majority of the water resource can be protected through purchase of only a portion of a watershed. Impacts upon upland areas, even if paved or otherwise heavily impacted, will impact a proportionally smaller amount of the basin's water and for a limited amount of time. Even if such upland impacts are permitted, protecting lowland areas will allow much of the upland pollution to be effectively filtered, especially in watersheds with significant downstream wetland areas.

However, hazardous substances (e.g., landfill leachate, petroleum product, etc.) introduced into a tributary may not be buffered simply by protecting downstream lands. The introduction of such materials is totally inappropriate on water supply drainages, even on upland sites. Reducing the risk of hazardous substances is best accomplished through watershed protection regulations and it is very likely that these types of pollutants will be minimized in the future.

MDC staff feel that non-point source pollution is likely to be the most significant pollution source in the future for private lands within the Quabbin watershed. This type of diffuse pollution, largely manifested in turbidity, nutrient loads, and low levels of organics and metals, is best prevented and mitigated through protection of key undisturbed drainage lands. The need for such protection is a strong argument for the future value of a well-designed land acquisition program. MDC Quabbin lands will primarily be influenced by pressure from increased recreational use which will increase the threat from the potential spread of human pathogens into the water. Within the Ware River watershed, uncontrolled commercial and industrial development of the upper watershed may be more of a concern than non-point pollution in the lower watershed.

b. Utilizing MDC Land Use/Water Quality Studies as a Guide

While the "varying source" model is a simple guide to efficient watershed protection, the "carrying capacity" for development, and the impacts of different land uses (e.g. housing, landfills, industrial, commercial, etc.) differ from one tributary drainage to another. For an efficient and effective acquisition program, these variables must be considered in the selection of appropriate land parcels.

The detailed MDC study of land use and water quality in five Wachusett tributary drainages strongly links water quality problems to inappropriate land usage (O'Gara 1989a and 1989b; Rondeau 1989; Rondeau and O'Gara 1990). The following overview of five Wachusett tributary drainages studied by MDC staff is instructive:

▹ Gates Brook Drainage (1,900 acres in West Boylston, Holden, and Worcester)

The Gates Brook drainage contains the largest percentage of developed lands of all Wachusett drainages (48%), including shopping centers, gas stations, auto body shops, a landfill, unsewered residential development, and farming. The stream is culverted in 37 locations, with many sites representing extensive wetland fillings. Much of this development is adjacent to or over the stream channel and associated wetlands. Gates Brook has the poorest water quality of any monitored tributary, with high recordings relative to other tributaries of turbidity, phosphorus, bacteria, nitrates, and chlorides. This drainage is an example of what may happen to other drainages without an aggressive land acquisition program. At this time, further significant acquisitions would be less effective and efficient in this drainage than in other drainages. MDC staff will focus on reducing pollution from present development where possible. In addition, the MDC is studying the possibility of constructing filter beds at the confluence with the Wachusett Reservoir.

▹ Muddy Brook Drainage (450 acres in West Boylston)

The Muddy Brook drainage is moderately developed, with land uses including an oil tank facility, unsewered residential development, an uncapped landfill, commercial development, and railroad and powerline easements. Much of this development (including the oil tank facility and landfill) is built adjacent to or on top of tributary branches and wetlands. While water quality monitoring has not occurred here, MDC staff feel that leaks from the oil tank facility and runoff from the landfill are the key threats to water quality. This site provides a good example of how major pollution-causing development - no matter where it is located in a drainage - can override the natural filtering processes of undeveloped land within a partially-developed drainage. With correction of pollution from the oil tank facility and landfill expected, further land acquisitions where future development is likely will help to protect the future water quality of this stream.

▹ Malden Brook Drainage (1100 acres in West Boylston)

The Malden Brook drainage consists of 14% developed lands, with land uses including gravel pits, paved roads, agriculture, unsewered residential development, and powerline easements. In general, the main impact in water-rich areas is agricultural and street runoff, and septic system effluent. Water quality measurements show low turbidity and moderate levels of phosphorus and nitrates. While many new homes have been built in the drainage, much of the water-rich land is undeveloped. Land acquisition, coupled with improved agricultural practices, could maintain and improve water quality.

▹ French Brook Drainage (1400 acres in Boylston)

The French Brook drainage consists of 94% undeveloped land. The 6% developed land includes a golf course, a tire dump, unsewered residential development, and paved roads. The main impact on water-rich lands is from the golf course and residences. Water quality measurements show low levels of phosphorus, nitrates, and chlorides. Turbidity is high relative to other Wachusett streams, possibly due to soils, drainage gradient, and land use. Land acquisition will be an important tool in maintaining existing good water quality in this drainage.

▹ Malagasco Brook Drainage (550 acres in Boylston)

The Malagasco Brook drainage is lightly to moderately developed, with land uses including a tree nursery, unsewered residential development, small dump and fill sites, and paved roads. The main impact upon water-rich lands is from the nursery and a multi-unit residential development, both situated near the stream. While water quality monitoring has not been implemented here, MDC staff feel that water quality can be maintained at a high level through the acquisition of key water-rich areas, and the regulation of existing and future land uses including non-point road runoff and nursery management practices.

c. Guidance from the 1986 Safe Drinking Water Act Amendments

Relative to the waiver of filtration, the SDWA Amendment Regulations note that a watershed should be owned by the water purveyor, or that agreements or regulations focused on private lands should be geared at adequately restricting activities or negative land uses. These regulations also state that both filtered and unfiltered water systems should strive for equal levels of watershed protection.

The regulations note that when ownership of the entire watershed is not possible, protection of critical areas may suffice. The SDWA Amendment Regulations differentiate between three zones within each watershed, defined as follows:

▹ Zone A, the most sensitive zone, includes all locations that fall within the 100-year flood of all 314 CMR 4.00 defined Class A tributaries, plus an additional setback of 400 feet above this boundary as an extra margin of protection during floods. In addition to this rule, an additional setback of one half mile or to the watershed boundary will be applied for high-slope areas where the average site-area equals or exceeds 24%.

▹ Zone B includes areas up to one half mile upgradient of the Zone A boundary.

▹ Zone C includes all areas not included in Zones A and B.

d. Goals for Identification of Final Watershed Protection Boundaries

Based upon the description of sensitive areas from both the SDWA Regulations and the hydrological literature, it is likely that by focusing protection on water-rich sites, actual water quality can often be protected. These water-rich areas are best suited to fee or easement acquisitions. However, in drainages where substantial development of less critical upland areas is possible and in drainages with limited wetland areas, protection of water-rich sites may not be enough. For example, it is possible for critical areas within drainages to be protected while substantial non-point pollution originates from upland impervious areas due to development. In these areas, large volumes of contaminated urban runoff may be channeled directly into water-rich areas. In these cases, a buffer zone between non-point pollution sources and water-rich sites may be essential in protecting tributary water quality. Serious point source pollution may override the benefits of any land protection program and should be excluded everywhere within the watersheds.

Each drainage has unique natural characteristics (e.g. slope, soils, wetlands) and an inherent "carrying capacity" for buffering of pollutants. In planning effective land acquisitions, the MDC must consider both the natural characteristics of each drainage and political factors such as zoning and development potential.

The following guiding criteria have been utilized in selecting fee/easement acquisitions necessary for the permanent protection of the integrity of the watersheds and to meet the 1986 SDWA Amendment Regulations. In setting priorities for each year, the threat of inappropriate development, proximity to reservoirs and intakes, and erodibility of the site will also be considered.

a. lands in Zone A as defined in the 1986 SDWA Amendment Regulations, including lands adjacent to Class A tributaries and 400 feet beyond the 100 year flood line surrounding them. In certain Zone A lands in headwater areas far removed from reservoirs and diversion intakes (referred to as Zone 2 areas in the MDC/MWRA 1991 Watershed Protection Plans) and where tributaries contain significant downstream wetlands, acquisitions will not be considered where sufficient watershed protection land use regulations exist,

b. lands in important tributary wetlands and aquifers not included in a. above,

c. lands in above Zone A in Class B tributaries where sufficient critical undeveloped land exists so that acquisitions can stave off further reductions in water quality and in drainages where MDC is not considering the construction of filter beds at the confluence with reservoirs,

d. lands in Zone B as defined in the 1986 SDWA Amendment Regulations (1/2 mile upgradient from Zone A) where significant development is possible and, due to the natural pollution-buffering capacity of the tributary (soils, wetlands, gradient, etc.), where watershed protection regulations alone will not protect the water quality at the tributary outflow,

e. lands in Zone B adjacent to existing development and important in filtering non-point urban runoff,

f. lands adjacent to MDC holdings which will improve efficiency of land management activities (e.g. boundaries, access, maintenance, forest management) and which also meet one of a.-e. above,

g. lands valuable for wildlife habitat, scenic amenities, open space, or which link public and private conservation areas, and which also meet one of a.-e. above,

h. lands where the Watershed Protection Act of 1992 has caused a loss of market value and which also meet one of a.-e. above.

Therefore, it is the goal of the Land Acquisition Program to protect critical water-rich areas (variable source and aquifer areas). In addition, it is the goal of this program to protect buffer zones between water-rich and upland sites in drainages where significant upland non-point pollution is possible.

3. Decisions Between Acquisition or Watershed Protection Regulation

The MDC's watershed land acquisition program includes the purchase of lands outright ("in fee"), and the purchase of easements ("less than fee"). Fee acquisitions afford the Commonwealth full privileges in land ownership, care, and control. Conservation easements constitute a partial acquisition of rights to land ownership, usually in the form of development restrictions. In these less than fee acquisitions, the MDC agrees to acquire limited rights to property and to record these rights as an attachment to a landowner's deed. The landowner remains the owner of record and retains all rights to ownership except those described in the easement. Conservation easements (often referred to as conservation restrictions or CR's) are held by the Commonwealth in perpetuity.

From the preceding discussion, it is clear that the specific watershed land protection approach should be molded to the local conditions of each drainage. For certain Quabbin drainages, whole remaining private holdings can be purchased in fee for relatively small expenditures. These purchases make sense from both a watershed protection and land management standpoint. In addition, revenues from appropriate forest management can make some of these purchases fairly cost-effective in the long term.

In many drainages at Wachusett and Ware River, a multi-faceted approach will provide excellent water quality protection, while remaining cost-effective. In these drainages, purchase in fee or purchase of easements is possible in the majority of undeveloped water-rich sites and should be a top priority. In drainages where access or existing protected open space limits upland development, purchases of water-rich lands alone may be adequate. However, many drainages have the potential for substantial development in upland areas. In these drainages, the purchase of key parcels and easements must be accomplished to further protect critical sites.

The regulations promulgated under the Watershed Protection Act (Chapter 36, Acts of 1992) limit, but do not preclude, development in critical watershed areas and some buffer zone areas. Therefore, the use of special watershed regulations alone is preferable in critical areas in the upper reaches of tributaries, and in buffer zones around water-rich sites in some areas.

An added benefit of the use of Watershed Protection Act regulations is that the placement of residences scattered throughout less critical areas of the watershed may substantially help in alerting the MDC to illegal activities in the watershed. In parts of the Quabbin watershed, large blocks of MDC land can be managed effectively. However, in much of Ware River and Wachusett watersheds, MDC holdings are scattered and will continue to be scattered, even after implementing an extensive land acquisition program. By allowing limited single-family residences, watershed monitoring may be improved.

In choosing between purchasing in fee or purchasing of easements, MDC will utilize the following guiding criteria:

Purchasing of Easements preferred:

- where landowners strongly prefer easements over outright purchase, and an estimated cost of 49 million dollars is the recommended minimum necessary to make land acquisition an effective part of the Watershed Protection Plan. In general, the majority of critical water-rich parcels ("varied source" and aquifer lands) are targeted for purchase. Decisions between fee and easement purchases will be based upon the above criteria. In drainages where substantial development exists or could potentially occur, purchases include critical areas and an adequate upland buffer between water-rich areas and development. In areas where the MDC already owns substantial holdings in a drainage and land prices are relatively low, purchase of remaining available lands is recommended. Utilization of new or upgraded Watershed Protection Act regulations as the sole form of protection is recommended only for water-rich areas in the upper reaches of the watershed (Zone 2) and in buffer zones between water-rich and upland sites in areas where limited development may be acceptable (Zone B).

The above program should take six years to complete with WPA bond monies. The MDC is currently reexamining long-range program priorities for the 7-15 year period, given the important protection offered by the WPA regulations and bond fund. The MDC has selected the following criteria to incorporate into a GIS model:

- distance to intakes,
- tributary buffers,
- aquifers,
- steep slopes,
- zoning.

The GIS model will numerically rate parcels on the three watersheds based upon these factors. An added criteria of "threats from development" will be used to reprioritize parcels as such threats become imminent. This model is being applied to the Wachusett watershed and will significantly increase the recommended acreage for acquisition in the long term.

While no easy rule of thumb for parcel selection can be derived from the land acquisition priorities outlined above, the parameter of wetland frontage protection is indicative. For example, currently MDC owns 49% of the approximately 216 miles of tributary and pond frontage within the Ware River watershed; an additional 9% is protected by other state have a demonstrated commitment to appropriate land management and protection,

- where tracking of enforcement of easements will be facilitated (e.g. areas near routinely maintained MDC lands or areas easily monitored by routine flyovers),
- where a new purchase of easement is adjacent to other MDC/DFW easement ownerships.

Purchase in Fee preferred:

- where water quality may be improved through direct MDC management (e.g. revegetation of riparian areas or appropriate forest management),
- where future checking of easement enforcement would be difficult or unlikely,
- where fee purchase would result in very low, long-term maintenance costs versus the cost of easement enforcement,
- where significant revenues could be obtained from appropriate long-term management,
- where traditional management of lands (e.g. agriculture), even utilizing best management practices, may be detrimental to water quality,
- where only minor cost differences exist between purchase in fee or purchase of easement,
- where a new purchase is adjacent to or surrounded by other MDC fee ownerships.

Summary of Recommendations

The amount of land to be purchased within each drainage, either in fee or by easement, will vary (see Table 3). For the three watersheds combined, a total of 15,961 acres of land at agencies and private conservation organizations (see Table 4). With the recommended purchase of 6,768 acres of land within the Ware River watershed (acreage comprising 13% of the total watershed), an additional 21% of the stream/pond frontage will be protected (see Tables 3 and 4). The net effect of the recommended purchase of 15,961 acres for all three watersheds (7% of the total land in the three watersheds) is indicated in Table 4, which demonstrates that in all three watersheds, the MDC is greatly magnifying the protection to wetland frontage through careful land selection. The level of protection gained by these acquisitions, together with additional regulatory and staffing changes recommended in the 1991 MDC/MWRA Watershed Protection Plans, will greatly increase the overall protection afforded the three watersheds and should be considered a minimum investment in watershed protection.

Land acquisition is one of the few public sector endeavors which is truly a one-time expenditure. By completing the purchase of the lands identified in this plan, the MDC will have acquired the "infrastructure" necessary to protect its water supply. As such, these acquisitions represent an extremely cost-effective expenditure for present and future generations. Just as the initial investment in land acquisition and facility construction was seen as essential to establishing the water supply, the current investment in land acquisition should be seen as a one-time investment to help protect this water supply in perpetuity.

4. Recommended Implementation Schedule for Land Acquisition and Associated Staffing/Consultant Costs

It is recommended that the acreage listed in Table 3 be acquired over the next six years. With a yearly expenditure of $8,000,000, the MDC would purchase approximately 2,700 acres of land each year. The MDC would require an annual expenditure of $600,000 on ancillary costs (land survey, appraisal, and title) to efficiently and effectively carry out this project. A schedule which is faster or slower than this will risk either poor project administration or loss of lands to development. In addition, it is recommended that three additional MDC engineering staff be hired to increase the MDC's in-house ability to do land surveys.

Table 3: Land Purchases (fee and easement) Recommended for Watershed Protection

WACHUSETT WATERSHED	ACRES	# PARCELS	ESTIMATED COST[1]	
Sterling	3608	173	$22,484,600.	
Boylston	680	15	3,437,170.	
Holden	1637	52	8,502,700.	
Princeton	1818	57	2,870,100.	
Subtotal	**7743**	**297**	**37,294,570.**	(avg. 4,817./acre)
WARE RIVER WATERSHED				
Hubbardston	3187	69	4,182,475.	
Oakham	5	1	8,000.	
Phillipston	931	10	807,500.	
Princeton	389	5	785,000.	
Rutland	1861	38	4,146,220.	
Templeton	395	9	712,400.	
Subtotal	**6768**	**132**	**10,641,595.**	(avg. 1,572./acre)
QUABBIN WATERSHED				
New Salem	400	4	900,000.	
Petersham	450	6	850,000.	
Shutesbury	250	4	475,000.	
Wendell	220	5	365,000.	
Orange	130	2	260,000.	
Subtotal	**1450**	**21**	**2,850,000.**	(avg. 1,966./acre)
ALL WATERSHEDS	15,961	450	50,786,820. Minus[2] 1,518,355. 49,268,465.	(All Watersheds avg. 3,087./acre)

---

[1] Costs were estimated using 1989 Dept of Revenue valuations, adjusted for specific site conditions where necessary. All parcels were mapped from town assessor maps.

[2] Deduction for reduced cost of conservation easements on an estimated 30% of the parcels at an average 10% reduction over fee costs.

Table 4: % Protected Lands and Wetland Frontage (rivers, streams and ponds) before and after implementation of MDC Land Acquisition Program; selected drainages in three watersheds.

WATERSHED/DRAINAGE	% LAND PROTECTED		% WETLAND FRONTAGE PROTECTED	
	BEFORE	AFTER	BEFORE	AFTER
Wachusett Watershed				
Gates Brook	5	5	26	26
Malden Brook	5	12	27	45
Quinnepoxet/Asnebumskit	25	45	29	58
Ware River Watershed (total)	42	55	58	79
Quabbin Watershed				
Hop Brook	30	42	54	81
Middle Branch	21	26	43	65
Moosehorn	82	91	91	93

[1] Includes MDC and other Public/Private conservation lands and easements.

B. Boundary Encroachment Monitoring and Resolution

Land boundaries represent the essence of the protection offered by lands purchased by the Commonwealth for watershed protection. If boundaries are not respected and if activities detrimental to the water supply occur, the value of MDC lands in protecting the water supply is seriously diminished.

The following list categorizes encroachments which have been reported at Division of Watershed Management boundaries:

- Water and Soil Impairment
  - dumping of debris and hazardous materials
  - storage of hazardous materials
  - grazing of animals, and manure storage

- Vegetation and Land Destruction
  - cutting/removal of trees and plants
  - damage to trees and plants
  - disturbance or removal of soil and ground cover
  - paving or covering of soil and ground cover
  - grading or filling land
  - removal of gravel or loam

- Construction
  - installation of fences
  - construction of sheds, cabins, walls, signs, docks, and buildings

- Boundary Marker Destruction
  - removal or destruction of stone and concrete markers, iron pipes, and line trees

Once an encroachment is discovered, a series of letters and field inspections are required in order to ensure compliance with the actions recommended by the Division. A small number of encroachments need to be resolved through court actions which require a great deal of additional police and Division staff time. Whenever possible, the Division strives to resolve encroachments outside of the court. The following table illustrates the location and character of encroachments discovered and completely resolved between 1988 and 1992:

WATERSHED	DUMPING, WATER QUALITY	CUTTING OF VEGETATION	BUILDINGS, SHEDS, FENCES, ETC.	TOTAL NUMBER OF INCIDENTS
Wachusett	3	2	0	5
Quabbin	1	3	1	5
Ware River	1	1	1	3
Sudbury	2	3	7	12
TOTAL	7	9	9	25

The bulk of the above encroachments were resolved in the period of 1988-89, when a civil engineer at Wachusett was assigned to investigate and resolve encroachments on a part-time basis. Most encroachments are discovered by field staff (e.g. civil engineers and foresters) while performing routine boundary marking or surveying areas where boundary lines are unclear. At this time, a number of obvious encroachments have been identified and have either been resolved orare in the process of being resolved.

The discovery of many more encroachments is anticipated as new lands continue to be acquired. In addition, there are many unidentified encroachments within the Sudbury watershed due to the length of time since most boundary lines were inspected, especially at Reservoirs 1 and 2. There are also local areas within the Quabbin, Ware, and Wachusett watersheds where exact boundaries are unclear and encroachments are likely.

There will continue to be new encroachments occurring along the hundreds of miles of existing boundaries in the four watersheds. It is felt that the best method of preventing new encroachments is swift and effective resolution of known encroachments.

Actions Necessary:

In order to reduce the number of encroachments, it is recommended that acquisitions with unclear boundaries be surveyed prior to purchase. At an average cost of $10,000 per survey, the Division must continue to dedicate significant resources to surveying as part of its land acquisition program. The addition of two MDC survey crews for land acquisition would have the double benefit of reducing contract costs associated with land acquisition as well as reducing boundary encroachments on newly acquired lands.

Currently, there are survey personnel at both the Division's Quabbin and Wachusett offices. However, these personnel also perform other duties including inspection of bridges, dams, and buildings, collection of water level and weather data, and contract supervision for repair and maintenance of facilities. Therefore it is recommended that two mid-level engineering staff be hired, one for Quabbin and one for Wachusett, so that the existing survey staff can focus on the backlog of boundary survey work needed on MDC lands. In addition, it is recommended that a higher-level engineering position be utilized to hire a Registered Land Surveyor (RLS) to work with both the Quabbin and Wachusett MDC survey crews so that recordable plans can be produced.

APPENDIX V. MDC LAND ACQUISITION PLAN, 1997-2007: WACHUSETT, QUABBIN, WARE RIVER, AND SUDBURY WATERSHEDS

Metropolitan District Commission
Division of Watershed Management

December 4, 1997

A. PURPOSE OF MDC WATERSHED LAND ACQUISITION PROGRAM

Over the past ten years since MDC has conducted a watershed land acquisition program, the basic purpose of this program has remained constant. The purpose is

> *to protect sensitive watershed land from urbanization and to restore and maintain stable forest cover on this land.*

Therefore, the chief value of this program is to help maintain high water quality into the future. While a few purchases allow for remediation of pollution sources, MDC generally does not purchase existing developed areas. The reduction of impacts from existing sources is accomplished through other programs within the Division outlined in the Watershed Protection Plans for the two reservoirs. The following two sections expand on the importance of the two key values of watershed land acquisition.

1. Protecting Water from the Impacts of Urbanization

Many studies document the negative impact of urbanization upon stream water quality. For example, Schueler lists significant changes to stream hydrology, morphology, and water quality after urbanization. These changes result in:

- peak discharges of from 2-5 times greater than pre-development,
- increased volume and rate of storm runoff,
- increased frequency and severity of flooding,
- widening of stream channels (Brach 1991; U.S. EPA. 1993; Schueler 1987).

Amount of impervious surfaces and type and location of land development and use are important factors affecting drainage water quality. Brach (1991) reported increases in the availability of several key pollutants after urbanization such as pathogens, suspended solids, nutrients, and metals. A key to the degradation of stream water quality is the percentage of impervious area associated with various types of development. For example, business or shopping center development may be 95-100% impervious, while high density residential development may be 46-60% impervious (Brach 1991).

Water quality monitoring at the MDC Wachusett Reservoir watershed supports the concept that increased development results in decreased water quality. In general, streams with significant acreage in development have lower water quality. Further, when sampling focuses on storm events, water quality results indicate even higher concentrations of parameters such as phosphorus and bacteria than in non-storm periods (Commonwealth of Massachusetts 1994). For example, Gates Brook within the Wachusett Reservoir watershed is the most heavily developed basin in the watershed (48% developed) and contains the poorest quality water of any tributary in the watershed.

2. The Value of Forested Watershed Buffers

Studies show that forested land provides superior water quality when compared to undeveloped open land (Carlton 1990; Dunne and Leopold 1978; Commonwealth of Massachusetts 1995). Van Miegroet and Johnson (1993) list the following attributes of forests which make them superior to agricultural cover in protecting water supplies:

- differential rooting patterns and depths,
- variation in annual return of organic matter and nutrients from canopy,
- periodic tree mortality,
- accumulation of forest floor organic matter,
- periodicities in above and below ground processes,
- temporal and spacial heterogeneity in soil properties.

Carlton (1990) examined the potential water quality differences between shrub and grass watersheds and forested watersheds. In forested watersheds, high infiltration capacities preclude most overland flow of water and a significant amount of the nutrient capital is locked into the forest vegetation and the thick layer of organic matter on the top layer of the soil. Forest canopy layers also function to reduce the erosive impact of rain drops, reduce excessive runoff through evapo-transpiration, and sequester significant amounts of airborne pollutants - the greatest source of pollutants in urban runoff. In herbaceous watersheds, due to a much reduced organic soil layer and increased runoff, a much higher percentage of runoff occurs as "quickflow" - either overland flow or rapid subsurface flow. The slower flow of precipitation through forested soils results in a less turbid water which is lower in dissolved substances eventually reaching the tributaries. The forest hydrologic process also tends to reduce the leaching of nutrients (Timmons et al. 1977).

Tributaries flowing through forested areas tend to be more stable and contain significantly greater amounts of woody debris (Sweeney 1993). Bormann et al. (1969) in studying a forested watershed in New Hampshire reported that debris pools, caused by dead and downed forest matter, occurred every 1-3 meters and could serve to slow the movement of suspended material and reduce the erodibility of the watersheds.

B. DESCRIBING SENSITIVE WATERSHED LAND

Modern hydrologic models show that land in and around tributaries, aquifers and wetlands will contain the greatest proportion of a basin's water, at any given time. The "varying source" model which describes most undisturbed New England small watersheds, emphasizes the importance of low lying, water-rich areas in contributing the majority of runoff during storm events through saturated subsurface and surface flow (Dunne and Leopold 1978; Hewlett and Nutter 1969). As a precipitation event continues, the area included in saturated flow increases. However, even in large storm events, the variable source still makes up less than the majority of the watershed, in most cases.

Studies show that pollutants added to the water-rich, "varying source" areas of small watersheds in New England, have a proportionately larger impact upon tributaries (Dunne and Leopold 1978). Therefore, development focused on these water-rich areas will have a proportionately larger negative impact upon the water resource. The logical conclusion of this discussion is that by focusing upon protecting variable source and aquifer areas, the majority of the water resource can be protected through purchase of only a portion of a watershed. Pollution sources on upland areas will impact a proportionally smaller amount of the basin's water and for a limited amount of time. Where urban runoff occurs in upland areas, forested buffers around tributaries will help filter pollutants before they enter streams.

The introduction of hazardous substances into a tributary (landfill leachate, petroleum product, etc.) may not be buffered simply by protecting downstream land. The introduction of such materials is totally unacceptable on water supply drainages, even on upland sites.

However, the reduction of the risk of the introduction of hazardous substances can be accomplished through watershed protection regulations, such as those of the 1992 Watershed Protection Act (Chapter 36, Acts of 1992), currently enforced on the Quabbin, Ware River, and Wachusett watersheds.

DWM staff feel that non-point source pollution is likely to be the most significant pollution source in the future for private land within MDC watersheds. This type of diffuse pollution (largely manifested in turbidity, bacteria and pathogens, nutrients, and low levels of organics and metals) is best prevented and mitigated through protection of key undisturbed drainage land and is a strong argument for the future value of a well-designed land acquisition program.

C. OVERVIEW OF MDC WATERSHED LAND ACQUISITION PROGRAM: 1985-97

From the completion of the Quabbin Reservoir project (1938) to the mid 1980's, MDC completed sporadic land acquisitions, generally triggered only when an especially critical parcel was endangered by development. Development booms in the 1950's and 1960's had significant impacts on the Sudbury and Wachusett watersheds. Consequently, cases of lowered water quality due to land development have been documented. For example, turbidity increases significantly as development increases in Wachusett drainages. East Wachusett Brook is 89% undeveloped and had an annual average turbidity of .3 Turbidity Unit (TU), while Gates Brook which is only 52% undeveloped had an annual average turbidity of 1.2 TU (EPA drinking water standards are 1 TU). Other parameters, such as phosphorus, nitrates, and chlorides, also tend to increase with development (Commonwealth of Massachusetts 1988; Camp et al. 1995).

The promulgation of the 1986 SDWA Amendment Regulations combined with the extensive building boom of the 1980's, were the key driving forces behind the watershed land acquisition program. The regulations specifically linked land ownership and management to necessary water supply protection, while the building boom represented an imminent threat to critical watershed land. Together, these two factors brought the need for this program into sharp focus.

The MDC Watershed Land Acquisition Program has been funded from three bonds: Commonwealth open space bonds established in 1983 and 1987 of 3 million and 30 million dollars respectively and a 135 million dollar bond established by the Watershed Protection Act of 1992. Land acquisition is paid for by the sale of Commonwealth bonds. However, while the annual bond payments are made out of the Commonwealth's General Fund, the Massachusetts Water Resources Authority (MWRA) reimburses the Commonwealth fully for these payments. The MWRA's contribution to watershed land acquisition was originally set at 50% by Chapter 372, Acts of 1984 and was increased first to 75% and then to 100% by the General Court in the late 1980's.

Although the 1983 and 1987 open space bonds included authorization for expenditures at the Sudbury watershed, this watershed's status as an emergency standby, inactive water supply meant that it received the lowest priority of the four watersheds. Therefore no funds from these bonds were spent on Sudbury land. The bond fund established by the Watershed Protection Act of 1992 only allows expenditure on the three active MDC watersheds. However, the recently enacted 1996 Open Space Bond includes an allotment of 10 million dollars for watershed land acquisition, part of which could be spent on the Sudbury watershed.

The following sections give an overview of plans and reports produced to assist in setting priorities for expenditures from the above funding sources.

1. Land Acquisition Report: 1987

The 1983 and 1987 open space bonds initiated MDC's current land acquisition program. The 1987 Open Space Bond Issue (Section 3 of Chapter 564, Acts of 1987) established a 30 million dollar account under the Executive Office of Environmental Affairs to purchase property in the Quabbin, Ware, Wachusett, and Sudbury watersheds for "the protection of the water resources of the Commonwealth". The General Court delegated responsibility for expending these funds to the Metropolitan District Commission (MDC) and the Division of Fisheries and Wildlife (DFW).

In joint meetings between MDC and DFW, it was agreed that water supply protection was the first priority in the expenditure of these funds. Because DFW's chief mandates are wildlife protection and enhancement, land which protected water and wildlife would be chosen, where possible.

In setting land acquisition priorities, DWM and DFW staff first defined a "water resources zone of influence" with the following criteria:

- proximity to water supply intake structure,
- proximity to surface water bodies,
- degree of slope,
- soil conditions,
- high rate of runoff,
- local zoning designation,
- developability.

Within the water resources zone of influence, the following criteria (in order of importance) were used to set priorities in selecting parcels for acquisition:

1. presently threatened by development,
2. contain a high degree of vulnerability to water resources degradation,
3. represent rare and endangered plant or animal species,
4. provide excellent habitat for diverse species of fish, wildlife, and wild plants,
5. abut existing MDC and DFWELE property,
6. provide continuous corridors between other public or private conservation land.

DWM forestry staff utilized existing topographic, wetland, aquifer, zoning, flood plain, soil, and assessors maps in identifying and mapping sensitive watershed land that met the above criteria. Table 1 summarizes the acreage and cost estimates contained in this report.

Table 1:
Breakdown of Recommended Acquisitions in 1988 Land Acquisition Report (French 1988).

Watershed	Total Acres Identified	Approx. Cost (millions of dollars)	Approx. Land Acquired with 33 Million Bonds	Approx. Cost (millions of dollars)
Wachusett	3,502	25.3 ($7,200/acre)	2,600	22.0
Ware River	6,903	11.0 ($1,600/acre)	3,800	7.0
Quabbin	3,697	4.8 ($1,300/acre)	1,900	4.0
Total	14,102	41.1 ($2,900/acre)	8,300	33.0

The overall estimates made in the 1988 report proved to be very accurate. From Fiscal Year (FY) 1987 through FY 1992, a total of 28.5 million dollars was spent to purchase 7,972 acres. The 1.5 million dollars spent to complete the 30 million dollar expenditure in FY 1993 added approximately 320 acres for a total acquisition of about 8,300 acres from the original 30 million dollars. The key accomplishments of this period of acquisition were holdings acquired along the lower Stillwater River at Wachusett, the East Branch of the Ware River in Ware River, and the West Branch of the Swift River in Quabbin. These areas were outlined as top priorities in the report.

2. Land Acquisition Plan: 1991

The Surface Water Treatment Rule contained in the 1986 Safe Drinking Water Act Amendment Regulations required MDC/MWRA to complete Watershed Protection Plans for Quabbin, Ware River, and Wachusett watersheds in 1991 (Commonwealth of Massachusetts 1991). These plans were required in order to file for a waiver of the filtration requirement under the new regulations. Land acquisition was a critical part of these plans because controlling or owning watershed land was an important requirement for receiving a filtration waiver.

Therefore, MDC completed a more extensive evaluation of land within the three active watersheds where acquisition was important for water supply protection (see Table 2). DWM staff utilized the same maps available for the 1988 report. In completing this analysis the following additional criteria were used in order to more closely follow guidelines contained in the policy written by the Massachusetts Department of Environmental Protection (DEP) for use in completing Watershed Protection Plans. This policy defined Zone A as the area that falls within 400 feet of the 100-year floodplain of all Class A tributaries and Zone B as the area located one-half mile upgradient from the Zone A boundary. Regions 1 and 2 are defined for each watershed, with Region 1 representing very sensitive watershed land near the aqueduct intakes. The following are the criteria, in priority order, used in this evaluation:

1. land in Zone A-1,

2. land in Zone A-2 that contain important tributary wetlands and aquifers,

3. land in Zones B-1 and B-2 where significant development is possible and, due

to the natural pollution-buffering capacity of the tributary (soils, wetlands, gradient, etc.) where watershed protection regulations alone will not protect the water quality at the tributary outflow,

4. land in Zones B-1 and B-2 adjacent to existing development which are important in filtering nonpoint urban runoff,

5. land adjacent to MDC/DFWELE holdings that will improve efficiency of land management activities (e.g. boundaries, access, maintenance, forest management), which also meet one of the above criteria,

6. land valuable for wildlife habitat, scenic amenities, and open space, which also meet one of criteria 1-4.

Table 2:
Breakdown of Recommended Acquisitions in 1991 Watershed Protection Plans for Wachusett, Quabbin, and Ware River Watersheds (Commonwealth of Massachusetts 1991).

Watershed	Acres	Estimated Cost (millions of dollars)	Acres Purchased Since 1991 WPP (FY 1991-7)	Actual Cost (millions of dollars)
Wachusett	10,500	46.2	6,924	51.4
Quabbin	1,020	1.6	1,343	3.4
Ware River	8,097	13.6	2,925	11.4
Total	19,617	61.4	11,192	66.2

In 1993, the above evaluation became incorporated in a schedule of implementation for the Wachusett Watershed Protection Plan. This schedule listed July, 1998 as the target for the acquisition of the 10,500 acres listed above. This date is also when DEP is scheduled to complete its evaluation of the waiver of the filtration for the Wachusett Reservoir. From FY 1991 to the date of this report, MDC acquired 6,924 acres in the Wachusett watershed or 65.9% of the 10,500 acres recommended in the 1991 plan.

Chapter 36 of the Acts of 1992, the Watershed Protection Act, states that land acquisition utilizing the act's 135 million dollar bond shall be consistent with procedures and priorities adopted by the Division or Commission relative to factors which may affect land and includes the following factors (the Act does not limit the Division to these factors alone in considering land for acquisition, however):

1. threat from development activities that endanger water supply water quality;
2. vulnerability to contributing to water resources degradation, whether by reason of proximity to water supply intake structures, proximity to surface water bodies, or degree of slope as related to soil erosion and flooding, soil conditions, and runoff rates;
3. protection of rare and endangered plant and animal species habitat;
4. protection of habitat for diverse species of fish, wildlife and wild plants;
5. immediate proximity to property now owned by the Commonwealth for the purpose of said division or said commission;
6. location as part of continuous corridors between public or private conservation lands; and
7. loss of market value by reason of the restrictions contained in this act.

At the same time that the Watershed Protection Plans were being completed for the three active MDC watersheds, a committee including Executive Office of Environmental Affairs (EOEA) land holding agencies and local non-profit land protection organizations assembled a proposal for improved coordination of management of EOEA land in the Sudbury region. This proposal included a request for land acquisition within the MDC Sudbury watershed. The request was based on a brief analysis of the availability of large parcels of open land which possessed important attributes for watershed protection (proximity to reservoir and tributaries and threat from development). This request included 348 acres with an assessed value of 3 million dollars ($8,600/acre). To date, none of the targeted parcels have been acquired although the Sudbury Valley Trustees has completed a large acquisition on Cedar Hill adjacent to Crane Swamp in the headwaters of the Sudbury Reservoir watershed and the City of Marlborough has completed an acquisition adjacent to their ski hill in the Marlborough

Brook sub-basin of the Sudbury watershed.

Tables 3 and 4 summarize land acquisition spending and acres purchased for the fiscal years since the inception of this program. FY 94 represented the first full year when MDC had expended the 1987 bond and began spending the 135 million dollar Watershed Protection Act bond.

Table 3: MDC Land Holdings by Watershed in 1985 and 1997[1]

Watershed	Acres (1985)	% of Watershed (1985)	Acres (1997)	% of Watershed (1997)	Total Watershed (1995)
Wachusett	5,608	7.9	13,624	19.2	70,934
Quabbin	51,792	54.3	54,203	56.8	95,411
Ware River	19,300	31.3	22,732	36.8	61,739
Sudbury	2,819	16.9	2,819	16.9	16,649
Total	79,519	32.5	93,378	38.2	244,733

[1] Figures from MDC GIS and other sources, current to date of report. Watershed totals exclude reservoir surfaces. MDC land outside of watershed boundaries is excluded. Sudbury watershed includes the land draining to Sudbury and Framingham Reservoir #3, but not Framingham Reservoirs #1 and #2, which are not part of the emergency supply.

Table 4: Land Acquisition 1985-97 for MDC Watersheds

Fiscal Year	Wachusett Acres MDC	Quabbin Acres MDC	Ware River Acres MDC	Total Acres MDC	Total Acres MDC and DFW	Total Cost MDC and DFW[1]
1985	51			51	51	.058[2]
1986						
1987	79	292	211	642	642	1.150
1988	24	77		101	101	.471
1989	498	105	107	710	710	6.006
1990	327	594	129	1,050	2,119	7.028 (4.600 MDC only)
1991	586	346	1,057	1,989	3,425	9.576 (6.400 MDConly)
1992	338	203	202	743	941	4.349 (3.800 MDC only)
1993	554	134	817	1,505	1,505	7.100
1994	820	410	632	1,862	1,862	8.356
1995	498	137	211	1,346	1,346	7.764[3]
1996	1,479	113	1	1,593	1,593	14.003
1997	1,668		5	1,673	1,673	13.679
1996	594			594	594	6.098
Total	8,016	2,411	3,432	13,859	16,562	84.638 (78.485 MDC only[4])

---

[1] All costs are in millions of dollars and include ancillary costs (survey, title, appraisal)

[2] reflects 3 million dollar 1983 bond issue - which was used to purchase 927 acres from FY 1985-89

[3] does not include taxes and interest costs for FY 94 and 95

[4] DFW acquired 2,703 acres on the three watersheds during FY 1990-2 at a cost of 6.153 million dollars.

D. LAND ACQUISITION PLAN: 1997

1. Introduction

Over the past twelve years MDC has significantly increased the acreage of its holdings within its three active water supply watersheds. Looking at MDC land as a percentage of the entire watershed, progress has been most dramatic in the Wachusett Reservoir watershed, where MDC holdings have more than doubled. During this period, MDC has consistently focused on "sensitive land" where development and urbanization could degrade water resources.

DWM has focused most acquisition monies on the critical Wachusett watershed during this period and in FY 1995 DWM implemented a policy which focuses nearly all acquisition effort on the Wachusett watershed. The policy restricts acquisition of land at Quabbin and Ware River watersheds to parcels where preparation work (title, appraisal, and survey) were completed prior to FY 1995. Exceptions to this policy are only made when important parcels are under imminent threat from development. This policy was put into effect for FY 1995-8 so that the Division can focus on protecting the Wachusett watershed over this period. After FY 1998, the Division will re-evaluate the allocation of the remaining Watershed Protection Act bond monies over the three active water supply watersheds.

As MDC initially owned so little land in the Wachusett watershed (less than 8% in 1985, a figure even lower than the Sudbury Reservoir watershed), a great deal of highly sensitive land was available for purchase over the first ten years of the land acquisition program. Over the past two years, MDC has refined a computer model to set priorities for land acquisition decisions within the Wachusett watershed. However, it is becoming clear that a policy of simply "acquiring the most sensitive remaining land" needs to be broadened to a more comprehensive watershed land protection strategy. Although MDC set a goal of ownership of 25% of the Wachusett watershed in its 1991 Watershed Protection Plan, this goal needs to be re-examined given the new MDC model for rating land sensitivity and consideration of other approaches to land protection that are now available. This section will expand on this idea.

The following section describes a model for setting land acquisition priorities and estimating the acreage of future MDC land necessary to adequately protect the Wachusett Reservoir. This model can be refined for the specific situations at the other three MDC watersheds to assist in completion of land acquisition programs at these watersheds after FY 1998, when DWM will re-examine its land acquisition focus across its four watersheds.

a. MDC Watershed Sensitivity Model

Clearly, there is a range of sensitivity of various watershed land to the impacts of development. For the past two years, MDC Division of Watershed staff have been refining a geographic information system (GIS)-based computer model which rates the relative sensitivity of land within the Wachusett Reservoir watershed. The project was begun with an in-depth analysis of the importance of various land criteria with respect to protecting the water quality of the Wachusett Reservoir. This analysis was completed by the Division Environmental Quality and Natural Resources Sections, together with MWRA staff. The five most important criteria were selected and after lengthy discussion revised based on the opinions of Division experts. The following are the five criteria selected:

Table 5: Version 1 of the MDC Watershed Land Sensitivity Model

Criteria	Sub-Criteria	Weights
distance to aqueduct intakes (A)	*Five "travel time" zones	5,4,3,2,1 with closest zone to reservoir = 5
Watershed Protection Act buffers around tributaries, flood plains and wetlands (B)	*0-200 foot zone *2-400 foot zone	3 2
aquifers (C)	low (1-100 gal/min) med (100-200 g/m) high (200-300 g/m)	1 2 3
town zoning (D)	commercial/indust. zones	3
slopes (estimated from USGS maps) (E)	greater than 15%	3

These five criteria were mapped and converted to digital data layers using ARC/INFO GIS software. Distance to aqueduct intakes was mapped utilizing a method described by Hakason et al. (1990). This method utilizes standardized surface water travel time information to map five zones within a watershed. Each zone is given a different multiplier. The zone closest to the reservoir was given a multiplier of 5, the next closest zone a multiplier of 4 etc. The following formula was applied to all of the land in the watershed:

$$A(1+B+C+D+E) = \text{Land Sensitivity Index}$$

where A = zone multiplier and B,C,D, and E are the criteria listed above.

The GIS analysis included indexes which ranged from 1 to 50 (the maximum possible index is 65). For each index the model mapped the location of land with that index and calculated the number of acres. The formula includes a constant of 1 so that all land in the watershed has an index of at least 1. This model was utilized to set priorities for land acquisition.

Recently, the Division Natural Resource and Environmental Quality Sections, together with MWRA staff, updated the above model. The new model has twelve criteria and three overlay basin multipliers. The new criteria considered new information on topics such as sewering, reservoir travel time, and stormwater pollution from the 1995 Camp Dresser and McKee report on water quality in the Wachusett Reservoir and up-to-date information on the proposed sewer system in West Boylston and Holden. The new model also maps presently developed areas. Although MDC does occasionally acquire developed land in order to restore sites, these are very sensitive and expensive acquisitions and must be done on a case by case basis. The new model also includes more accurate mapping of topography and hydrology based on MDC orthophotography.

As each of the twelve criteria and three overlay districts has a different value to MDC and MWRA staff in setting priorities for land protection, the Analytical Hierarchy Process (AHP) (Saaty 1990) was used to weight the importance of criteria and overlay districts. AHP is a decision-making technique which utilizes "pairwise comparisons" of all combinations of criteria and complex matrix algebra to fairly represent expert judgements in weighting different criteria. For this model, the process involved consensus agreements among MDC and MWRA technical staff on 69 "pairwise comparisons" among the different criteria and overlays. The reasoning behind the group consensus for each of these comparisons was recorded to be used in any future model revisions. The criteria and weights are listed in Table 2.

Using the weighted criteria and overlay districts, a "land sensitivity index" was calculated by adding the overlapping weights of all criteria for a given land area and multiplying this number by the weight number for the overlay district in which that land falls. For example, the highest scores will occur where several highly weighted criteria occur in the most important overlay district. Over 35,000 different polygons representing different criteria combinations were mapped and analyzed. The following formula was used to calculate the "land sensitivity index" for a given area of land with similar overlapping criteria within a given overlay district:

$$1,2, \text{ or } 3(A+B+C+D+E+F+G+H+I+J+K+L) = \text{Land Sensitivity Index}$$

In order to utilize the "land sensitivity index" in a land protection strategy, the following technique was utilized. As all land in the watershed has a discrete "land sensitivity index", the number of acres of land with one index was multiplied by the index. For example, if 125 acres have an index of 45, these two figures will be multiplied. This process was completed for all land in the watershed to calculate a total figure for the entire watershed. The figure for developed land will be separated from other watershed land. Next, the existing acreage of MDC land will be multiplied by the respective indices to come up with a total "land sensitivity" for all MDC land. The same process will be done for "other protected land" in the watershed. Next, the combined "land sensitivities" for MDC and other protected land will be divided by the total "land sensitivity" for the entire watershed. In this way, the percentage of the total "land sensitivity" protected can be calculated. This percentage will be a more accurate reflection of the actual water quality protection offered than the traditional percentage of total watershed acreage protected.

In order to determine the percentage of the total "land sensitivity" of the entire watershed that should be in protected land, a number of techniques can be utilized. For example, a graph can be produced by plotting discrete "land sensitivity indices" on the X axis and the number of corresponding acres on the Y axis. A point on this curve where additional acres yields very little additional "land sensitivity" could be found. A strong argument could be made that the appropriate use of land acquisition would be to purchase the land up to the point of "diminishing returns" with regard to "land sensitivity".

Table 6: Version 2 of the MDC Watershed Land Sensitivity Model[1]

Criteria	Criteria	Weight[2]
A	8% or greater slope	.088
B	low yield aquifers	.013
G	med/high yield aquifers	.061
D	HD res zone and unsewered	.072
F	HD res zone and sewered	.027
F	Comm/Ind zone and unsewered	.107
G	Comm/Ind zone and sewered	.039
H	0-200 WPA buffer	.136
I	2-400 WPA buffer	.088
J	0-200 non-WPA buffer	.278
I	2-400 non-WPA buffer	.150
L	Other watershed land	.011

Overlay Basin	Overlay Basin	Weight
J	Worcester Water Supply Basin	.056
2	Central Wachusett Basin	.013
3	Route 12 Bridge Basin	.701

[1] The above weighting figures are preliminary and will be adjusted in the near future. These criteria and weights represent staff analysis for the specific conditions at the Wachusett Reservoir and may not be applicable elsewhere.
[2]using the Analytical Hierarchy Process

Another way to use the model to assist in land acquisition decisions is to estimate the acreage which could be purchased with the remaining bond monies. Next, the highest scoring undeveloped land of that acreage size is mapped using the model. DWM staff estimate that approximately 17,000 acres could be purchased with remaining funds. Of this land, it is estimated that 13,000 acres of high priority land could be purchased and that approximately 4,000 acres of contiguous, lower priority land would be purchased within these parcels (even when MDC strives to "survey out" lower priority land from targeted parcels). The following table is a comparison of MDC, other protected openspace, and future MDC land acquisitions (the 13,000 highest scoring acres).

Table 7: Comparison of Land Ownership and Land Sensitivity Protected[1]

Current MDC % of Watershed	Current MDC % of watershed land index	Openspace % of Watershed	Openspace % of watershed land index	Future MDC % of watershed	Future MDC % of Watershed land index
19.3%	29.5%	27.7%	24%	33%	62%

[1] Figures for % of watershed do not include Wachusett Reservoir. Openspace is land protected by non-MDC state agencies, water utilities, towns, and private non-profits.

It is estimated that if the 13,000 acres with the highest scores were purchased, approximately 76% of the land sensitivity of the watershed would be protected (including MDC and other protected openspace lands). This figure appears to reflect a high level of protection of sensitive watershed resources. However, when the "land index" and percentage of monies expended are graphed, it appears that there is a diminishing returns in the amount of watershed protection purchased with remaining funds. For example, if 10% of the remaining funds were used to purchase the highest scoring remaining lands, they would protect approximately 25% of the remaining sensitive watershed resources, as measured by the model. Conversely, the last 10% of remaining funds would only purchase 6% of the remaining sensitive watershed resources. As the model is refined, it will be useful in determining the value of purchasing additional watershed land. It is clear that this type of analysis will be more useful in guiding land acquisition decisions than a simple rule of thumb such as ownership of 25% of the watershed lands.

This model was developed for the specific conditions that exist at the Wachusett Reservoir watershed. The model is also affected by the availability of accurate map overlays. Therefore, the basic approach described above to assessing the sensitivity of watershed land can be transferred to other watersheds with input of unique site conditions and given existing map overlays.

2. Additional Techniques for Assessing and Protecting Watershed Land

a. Land Planning and Analysis

MDC is employing planning and engineering firms to map sensitive resources and development constraints on some of the remaining large parcels (150+ acres) in the watershed. This work includes mapping and percolation testing of soils, flagging of state-protected wetlands, and mapping of other sensitive resources and development constraints. This information is used in the drafting of development plans which highlight low impact approaches. The project will assist MDC in locating land where acquisition is necessary and in helping to reduce impacts on less sensitive land.

b. Individual Parcel Analysis

MDC has employed a consultant hydrogeologist to assess the impact of a specific proposed development on a parcel being considered for acquisition. Individual parcel analysis will be used on lower priority parcels which are threatened by intensive development (multi-family, commercial, etc.). In the long term, this type of parcel by parcel analysis may be useful in determining the need for protection after the overall land acquisition goals have been attained. Parcel analysis may involve detailed mapping of local hydrology, analysis of site soil and surficial geology, and/or modeling of pollution impacts of proposed development.

c. Private Forest Land Protection

MDC completed an outreach program to private forest landowners on the Wachusett watershed and part of the Ware River watershed. During FY 96, MDC employed a forester who contacted over 600 persons who owned 12 acres or more of forest land. These persons collectively own over 32,000 acres or one third of the estimated 96,000 acres of private, unprotected forest land which makes up 42% of the three MDC watersheds. The intent of this program was to increase the acreage of private forest land protected by the Massachusetts Forest Tax Law (Chapter 61).

Chapter 61 requires landowners to complete a professionally-prepared forest stewardship plan and make a ten year commitment to keeping the land in forest cover and completing necessary management to improve forest condition. During the ten year period, the town holds a lien on the land and the land taxes are reduced to only 5% of their previous level. Once in the program, the town and MDC have the first rights to purchase the land should it be taken out of classification. If the landowner decides to withdraw land from classification, back taxes plus a penalty are due. Thus increasing land in the Chapter 61 classification increases the protection to the reservoir.

As a result of this effort, forest management plans were completed for 1,849 acres in the two watersheds. To date, 351 acres have been added to Chapter 61 classification as a result of the program. An additional 573 acres for which plans have been completed are eligible for Chapter 61 status and may be added to this classification, depending on the wishes of the landowners.

DWM is continuing the private forest land program using an existing staff person on a part-time basis. DWM plans to contact the owners of the remaining 64,000 acres of private, unprotected forest land over the next ten years and fund forest management plans and certain watershed protection forest practices for interested land owners.

3. Applying Appropriate Layers of Protection

Once the sensitivity of various watershed land has been assessed, targets for various types of land protection can be specified. This protection strategy is meant to eliminate significant threats from potential development and will include the following tools: acquisition of MDC fee or conservation restriction (CR), acquisition of fee or CR interests by a non-profit conservation organization, signing of protection agreements between MDC and land owners, and utilization of state or local laws and regulations which protect water and forest resources.

In order of priority, the land protection strategy will be to:

1. purchase by MDC of fee or CR interests in land containing most of the "sensitivity to development" within the watershed, as determined by its GIS model,

2. complete land planning and analysis projects on remaining large parcels in the watershed in order to more accurately map sensitive resources for acquisition and to encourage low impact land uses on less sensitive land,

3. encourage non-profit conservation organizations and other governmental

agencies to purchase fee or CR interests in less sensitive watershed land, where possible,

4. negotiate land protection agreements or CR's with non-profit conservation and other governmental agencies owning land within the three watersheds,

5. implement Watershed Protection Act regulations on all applicable land,

6. assist private forest landowners of less sensitive watershed land in meeting requirements for M.G.L. Chapter 61 (Forest Tax Law) in order to reduce the likelihood of future land development,

7. encourage towns to enact and implement bylaws which protect land from the impacts of development and urbanization.

E. MDC CONSERVATION RESTRICTION POLICY

The MDC'S watershed land acquisition program includes the purchase of land outright (in fee), and the purchase of easements (less than fee). Fee acquisitions afford the Commonwealth full privileges in land ownership, care, and control. The full and fair market value is paid for all rights to land in a fee acquisition.

Conservation easements, on the other hand, constitute a partial acquisition of rights to land ownership, usually in the form of development restrictions often referred to as conservation restrictions or CR's. In these cases, the MDC agrees to acquire limited rights to property and to record these rights as an attachment to a landowner's deed. The landowner remains the owner and retains all rights to ownership except those described in the easement. This is a less than fee acquisition.

Of paramount importance to the MDC is the protection of water quality. Any easement acquired by the MDC for watershed protection must help insure the maintenance of a pure public water supply. To this end, it is the policy of this agency to expend funds for the purchase of conservation easements only on acreage with uses both present and projected that do not conflict with this goal. Land uses expressly excluded from consideration for easement purchases include:

- dwellings
- septic systems and leach fields

- storage, stockpiling, or use of hazardous materials, petroleum products, pesticides and herbicides, manure and fertilizers
- livestock
- tillage
- excavation of gravel, loam, peat, and/or rock except as incidental to land maintenance
- use by the general public of motorized all-terrain vehicles including snowmobiles, 4WD recreational vehicles, and motorcycles (MDC assistance with gates and signs may be available upon request)
- timber harvesting or tree cutting not in compliance with the Massachusetts Forest Cutting Practices Act (M.G.L. Ch 132) and MDC Best Management Practices for forest management.
- any other uses considered to be detrimental to the watershed by the MDC or future holders of the easement.

Continued use of the property by its owners for forestry, wildlife, recreation, and privacy purposes is encouraged. Conservation easements do not require owners to make their land accessible to the public, but the MDC reserves the right to periodically enter the property to inspect for continued compliance.

Conservation easements are held by the Commonwealth in perpetuity, and serve to protect vital resources for future generations.

The conservation easement can serve as an important tool for many landowners in the arena of tax and estate planning. A consultation with a qualified estate planner is advised.

F. CRITERIA FOR UTILIZING FEE AND CONSERVATION RESTRICTION ACQUISITIONS

In choosing between purchasing of fee or easements, MDC will utilize the following criteria:

Conservation Restrictions (CR) Preferred:

a. where landowners strongly prefer CR's over fee and have a demonstrated commitment to appropriate land management and protection,

b. where an acquisition is adjacent to other MDC CR's,

c. where future public access may present a potential water quality threat, and/or

d. where there is a significant cost difference between a fee and CR.

Fee Preferred:

a. where landowners have not demonstrated a commitment to appropriate land management and protection,

b. where water quality may be improved through tightly- controlled MDC management (revegetation of riparian areas, restoration of eroding slopes, or appropriate forest management),

c. where future monitoring of CR's would be difficult,

d. where a fee acquisition will result in very low, long-term maintenance costs when compared to CR monitoring costs,

e. where future public access does not present a significant potential water quality threat,

f. where significant revenues could be obtained from appropriate long-term management,

g. where landowners cannot continue to utilize land and meet strict MDC CR requirements (such as cattle or horse grazing),

h. where only minor cost differences exist between purchase of fee or CR, and/or

i. where an acquisition is adjacent to or surrounded by other MDC fee ownerships.

APPENDIX VI. EOEA ARTICLE 97 LAND DISPOSITION POLICY

August 1, 1995

I. Statement of Policy

It is the policy of EOEA and its agencies to protect, preserve and enhance all Article 97 land owned and held in the name of the Commonwealth of Massachusetts. Accordingly, as a general rule, EOEA and its agencies shall not sell, transfer, lease, relinquish, release, alienate, or change the control or use of any right or interest of the Commonwealth in and to Article 97 land. Exceptions shall be governed by the conditions included in this policy.

An Article 97 land disposition is defined as: a) any transfer or conveyance of ownership or other interests; b) any change in physical or legal control; and c) any change in use, in and to Article 97 land or interests in Article 97 land owned or held by the Commonwealth, whether by deed, easement, lease or any other instrument effectuating such transfer, conveyance or change. A revocable permit or license is not considered a disposition so long as no interest in real property is transferred to the permittee or licensee, and no change in control or use occurs thereby.

II. Conditions for Disposition Exceptions

EOEA and its agencies will consider an Article 97 land disposition only under exceptional circumstances. The determination of an Article 97 land disposition and what constitutes an "exceptional circumstance" rests solely with EOEA and its agencies, subject to all of the following conditions being met:

1. the disposition of the subject parcel and its proposed use do not destroy or threaten a unique or significant resource (e.g., significant habitat, rare or unusual terrain, or areas of significant public recreation), as determined by EOEA and its agencies;

2. as part of the disposition, resources of significantly greater value are protected, as determined by EOEA and its agencies, either through acquisition of additional Article 97 land or through other means, so that

the mission and legal mandate of EOEA and its agencies are protected and enhanced;

3. to the extent possible, the resources of the parcel proposed for disposition continue to be protected;

4. the disposition serves an Article 97 public purpose or another public purpose without detracting from the mission, plans, policies and mandates of EOEA and its appropriate department or division;

5. the disposition of a parcel is not contrary to the expressed wishes of the person(s) who donated or sold the parcel or interests therein to the Commonwealth.

III. Procedures for Disposition

Although legislation can be enacted to dispose of Article 97 land without the consent of an EOEA agency, it is the policy of EOEA to minimize such occurrences. To that end, and to ensure coordination, EOEA agencies shall:

1. develop an internal review process for any potential Article 97 land disposition to ensure that, at a minimum, the conditions in Section III above are met;

2. develop, through the Interagency Lands Committee, a joint listing of all requests, regardless of their status, for the disposition of Article 97 land;

3. notify the Interagency Lands Committee of any changes to the Article 97 land disposition list;

4. monitor all legislation that disposes of Article 97 land, and communicate with legislative sponsors on their intent;

5. recommend to the Secretary that the Governor veto any legislation that disposes of Article 97 land on and for which the EOEA agency has not been consulted and received documentation (including appropriate information on title, survey, appraisal, and MEPA requirements, if any);

6. obtain the concurrence of the Secretary of EOEA for any proposed Article 97 land disposition decision prior to finalizing said decision;

7. notify, in writing, legislative sponsors (if any) and the Secretary of EOEA of any EOEA agency approvals (with any conditions) or disapprovals of proposed dispositions of Article 97 land, including justification of such action;

8. recommend to the Secretary that the Governor veto legislation that disposes of Article 97 land of which the agency disapproves;

9. ensure that any conditions approved by EOEA and its agencies to any Article 97 land disposition are incorporated within the surplus declaration statement submitted to and published by DCPO as required by G.L. c. 7, ss. 40F and 40F1/2; and

10. ensure that any Article 97 land disposition is authorized by enacted legislation and approved by all local, municipal, state and federal agencies, authorities, or other governmental bodies so required and empowered by law.

Trudy Coxe, Secretary
Executive Office of Environmental Affairs

APPENDIX VII: FOREST FIRE POLICY

The *purpose* of this policy is to provide all MDC personnel involved in fire control activities with the guidelines and procedures followed by the MDC in wildfire suppression.

The *goal* of this policy is to protect and minimize damage from potential wildfires on Division of Watershed Management Lands and to conduct all fire suppression activities in an efficient and safe manner with trained MDC fire crews, working in cooperation with State and local fire suppression organizations.

The *objective* of this policy is to promote a cooperative effort within the MDC between clerical, police, ranger, labor, and forestry personnel, as well as a productive, cooperative relationship between the MDC and local fire departments. This will require training for MDC personnel and possibly training with local fire departments. Periodic review of our policy will be undertaken to improve our cooperative efforts within the MDC.

POLICY:

I. When a fire is reported on MDC land during regular working hours, notify:

a) the Administration Office and the State Police at Quabbin

Radio:
C-7 Windsor Dam - State Police, Quabbin
Quabbin Base - Administration Office

Phone:
413-323-7561 - State Police, Quabbin
413-323-6921 - Administration Office

b) At all other times, notify State Police at Quabbin (as above)

II. The information as reported will be conveyed by the Administration Office or State Police Quabbin to:

a.) The local Fire Department nearest to the reported location.

Quabbin Reservoir Watershed Town Fire Departments:

Barre	978-355-4574
Belchertown	413-253-3433
Hardwick	413-477-6444
Hubbardston	978-928-3333
Orange	978-544-2727
Pelham	413-253-3311
Petersham	978-724-3232
New Salem	978-544-2500
Shutesbury	413-253-3652
Ware	413-967-5901
Wendell	978-544-3212

b.) DEM Division of Fire Control, Radio Room:

1-508-464-2987 or 1-617-727-3189

c.) MDC Fire Coordinator
Radio - MDC 960
Telephone (New Salem Headquarters): 1-978-544-6343

or

MDC Chief Forester
Radio - MDC 912
Telephone (New Salem Headquarters): 1-978-544-6343

d.) Quabbin Superintendent
Telephone (Quabbin Administration Office): 1-413-323-6921

III. The Fire Coordinator or Senior Forestry staff person will assist the local Fire Department in locating the fire, coordinate suppression effort with DEM and local Fire Departments, and determine the MDC personnel and equipment necessary to suppress and mop up the fire. The Fire Coordinator will supervise all MDC staff working at the fire scene.

FIRE CONTROL PROCEDURES

Consistent with Massachusetts State Law, the Forest Fire Warden (usually the Fire Chief) of the town in which the fire is located is in charge of the fire unless the Warden releases that authority to the MDC. Until such time, the MDC Coordinator will assist the Forest Fire Warden with equipment and personnel as required. In most cases the Forest Fire Warden will release authority to the MDC for mop-up operations. When this occurs, the MDC Fire Coordinator will set up a patrol of the burned area and thoroughly cool all hot spots until there is no possibility that the fire will reignite

During all phases of the fire suppression activities, the Fire Coordinator will determine the necessary levels of MDC personnel and equipment. The Fire Coordinator will be assisted by MDC staff in order to arrange for personnel, equipment, and supplies.

The Quabbin Fire Tower is no longer a functioning wildfire detection station. The MDC and DEM Division of Fire Control have determined that the best coverage for detecting and locating wildfires on the Quabbin Watershed will be attained by staffing the towers on Mt. Lincoln in Pelham and Mt. Grace in Warwick. These towers, in conjunction with the Wachusett tower in Princeton, provide adequate coverage when utilizeded by trained personnel. The MDC will support the operation of these towers during periods when severe wildfire threats exist by providing staff, trained by DEM, to operate the Mt. Grace and/or Mt. Lincoln towers. The Quabbin Superintendent will determine the level of commitment the MDC is able to provide. Training of tower personnel will be arranged through the Fire Coordinator. The Superintendent and Fire Coordinator will determine the yearly budget requirements of the forest fire crews.

SPECIAL SITUATIONS

Fire On Reservoir Shoreline or Islands

The Fire Coordinator is authorized to use the Fishing Area utility boats and available rental boats for use in transporting personnel and equipment to and from fire scenes with difficult land access. Area II would be the primary area of use, but any Area may be utilized for fires as determined by the Fire Coordinator.

Structure Fires

Structure fires on MDC property will be dealt with by local Fire Departments. Only the Senior Management person on duty would be notified and would make decisions according to the specific situation.

Closure of MDC Watershed Lands due to Extreme Fire Danger

If conditions warrant, the MDC retains the power to close all recreational activity upon the lands and waters under its control. When extreme fire danger exists, the Quabbin Superintendent will order the closure of all Quabbin Section MDC Division of Watershed Management lands. The closure would include all land-based recreational and research access, including shore fishing and beaching of fishing boats for any purpose.

The closure of the watershed to all visitors is deemed an extreme measure and would only be called for in time of drought or when the DEM Division of Fire Control and the MDC have determined that the action is necessary for the protection of the watershed.

The Quabbin Section sign shop will have available at all times an adequate supply of signs designating "Area Closed due to Extreme Fire Danger" for posting the Quabbin and Ware River Watersheds.

Upon closing of the watershed, the Fire Coordinator and designated foresters trained in wildfire control will patrol the area to inform the public of the closure, and will be prepared to respond to any incidents that occur.

FOREST FIRE CREWS

Normally, an MDC Forest Fire Crew will contain 6-10 personnel under the direction of a trained crew leader (Red Card obtained through MDC sponsored training with the U.S. Park Service). The crew will be adequately trained and dressed, with MDC-issued work shoes, longsleeved shirts, hardhats, and gloves. Fire resistant overalls will also be available and will be used as ordered by the Fire Coordinator.

The crew leader will familiarize the crew with as many details of the fire fighting process as possible. This will enable the crew to extinguish the fire in an efficient, effective, and safe manner.

The Fire Coordinator, assisted by Forestry and DEM Division of Fire Control staff, will train all crew members including designated truck drivers on the operation of the fire truck and its pumps, gates, valves and hoses.

FIRE TRAINING PROGRAM

It is the belief of this administration that all MDC employees who respond to a working fire or assist in fire cleanup must be adequately trained and clothed. It is important for the safety of the individual, and the crew as a whole, for each member to be familiar with the basic operations of a fire crew and to recognize basic fire behavior patterns. Each employee must also have knowledge of the basic fire fighting tools and their correct use and limitations. It is to this end that the Division of Watershed Management holds yearly classroom instruction and field training in various aspects of fire control. These training sessions have been taught by members of the Massachusetts DEM Division of Fire Control, as well as the National Park Service and University of Massachusetts staff.

In addition to the formal training described above, each year the MDC Fire Crew with the assistance of University of Massachusetts and/or DEM Division of Fire Control, Massachusetts Division of Fisheries and Wildlife, the National Park Service, and The Nature Conservancy, have conducted *controlled management burns* on designated watershed lands. Controlled management burns allow the MDC to fulfill two objectives. First, controlled burns allow the training of personnel in a real fire environment. There is no substitute for training received on an actual fire. Constructing fire lines, using backpack pumps and other hand tools on an actual fire situation allows the individual an opportunity to judge the limitations of the equipment as well as to directly observe fire behavior patterns. Second, the use of fire as a management tool has been recognized by a growing number of land management organizations as an effective means to maintain certain desired habitats. The Nature Conservancy has taken a lead role nationally in using fire management techniques to maintain habitats of endangered species. Where appropriate, MDC will utilize these techniques to meet similar objectives.

REQUIRED FIRE TRAINING

Each member of a Fire Crew must receive formal Forest Service Red Card Training from a certified instructor. To maintain certification, each member must also participate in one controlled burn or one active wildfire every two years. Failure to meet these standards will result in the employee being dropped from the Fire List. Any substitution of courses or experience must be approved by the Fire Coordinator, the Chief Forester and the Superintendent.

FIRE APPARATUS

MDC 960 - 1996 4 x 4 1/2-ton truck Emergency Communications Unit
MDC 998 - 1994 4 x 4 1-ton utility truck with Wajax 100-gallon Fire Tank
MDC 999 - 1994 4 x 4 1-ton utility truck with Hale float pump and hose
MDC 925 - 1979 Ford Flatbed/Wajax 200-gallon fire tank
MDC 953 - 1987 John Deere Skidder/Felco 250-gallon Fire Tank
MDC 926 - 1995 Mack Dump Dump/tilt Trailer

These units will be stationed at MDC Forestry Field Office in New Salem and will be the responsibility of Fire Coordinator. Repair and maintenance of the trucks will be the responsibility of the MEM II. The vehicles will be started monthly and all necessary repairs and service will be performed as needed.

MDC 945 - 1964 Ford Fire Truck
MDC 915 - 1988 4 x 4 Dodge Pickup with Wajax 100-gallon fire tank

These units will be stationed at the Administration area in Belchertown. Repair and maintenance of the trucks will be the responsibility of the MEO III. Vehicles will be started monthly and all necessary repairs and service will be performed as needed.

Any time the apparatus is found not "fire ready" the Fire Coordinator will be notified immediately, in writing, stating the nature of the repairs and a cost estimate of repairs needed.

FUTURE EQUIPMENT NEEDS

The Quabbin Section has been upgrading the equipment now in its possession to make it compatible with equipment in use by local fire departments and the DEM Division of Fire Control. This has been accomplished by the purchase of 1.5 inch "Hotline Fire Hose" that is the industry standard for wildfire suppression, and the inclusion of two additional floating fire pumps, and two 100-gallon slip-on fire tanks.

To increase the ability to control wild fire in remote areas, the MDC purchased a Felco Fire Tank to be used on the existing John Deere 4WD log skidder. This self-contained unit with a 250-gallon capacity tank is equipped with a hydraulic pump, operating from the skidder hydraulics, that enables it to draft water from any water source and pump water through the 200 feet of 1-inch hose on the attached hose reel. This unit has been tested on several controlled burns and has proven to be an effective addition to the wildfire control arsenal.

Each year the addition of hand tools, backpack pumps, fire hose, and safety clothing will be undertaken as the budget allows. This replacement of tools is an ongoing process to keep the fire-fighting crews equipped with the most modern and effective equipment available.

APPENDIX VIII. GATE INSTALLATION /ROAD CLOSURES AND MAINTENANCE

A. ROAD CLOSURE AND GATE INSTALLATION

It has been the MDC policy for Quabbin to support the abandonment of town and county roads through the watershed when there is agreement among town officials and abutters to do so. Once roads are abandoned, it has been MDC policy at Quabbin to install gates as close to MDC property boundary lines as is logistically possible (given gate location and parking considerations). Gates minimize problems associated with vehicle access such as rutting and erosion and illegal dumping. Over the past ten years, 48 steel gates have been installed at Quabbin, 16 for closure of newly acquired or abandoned roads and 32 for replacement of existing gates in poor repair.

The following roads have been abandoned by the local towns within the past 10 years. During this time, the MDC had an active land acquisition program to purchase scattered private parcels that were accessed from these roads. Once the lands were purchased, the MDC installed gates to control vehicle access. These roads are all part of the watershed drained by the West Branch of the Swift River; Rocky Run, Camel, Canada, and Village Brooks are the most important tributaries to the West Branch.

Road	Drainage	Town	Miles of Road
New Boston	West Branch	Shutesbury/Wendell	3.2
Mt. Mineral	West Branch	Shutesbury	1.0
Freeman	Rocky Run	Shutesbury	1.6
Camel	Camel Brook	Shutesbury	1.2
Macedonia	Canada/Village Br.	Shutesbury/New Salem	2.2
N. Macedonia	Canada Br.	Shutesbury	1.6
Rockwell Hill	West Br./Canada	Shutesbury/Wendell	1.4
West Main	Canada Brook	New Salem	0.3
Gage Lane	Canada Brook	Wendell	0.8
			Total 13.3

B. ROAD MAINTENANCE

The woods road system is essential, providing access for key Quabbin watershed management activities including fire protection, ranger patrols, water quality sampling and forest management. The proper maintenance of woods roads can greatly reduce the deposition of sediment and organic matter into nearby tributaries.

The MDC Quabbin watershed lands have a woods road system in excess of 200 lane miles which provide vehicle access throughout most of the watershed area. These roads date to the pre-reservoir communities, and many were well-constructed, well-drained roads which have been uprgraded and maintained by MDC Watershed Maintenance Staff. A myriad of farm lanes, logging roads, and seasonal access roads provide emergency and limited seasonal access to large tracts of forested watershed. Of the 58,000 acres of MDC Quabbin lands, approximately 687 acres is in woods roads; by management blocks, this breaks down to 134 acres in Prescott, 130 acres in Hardwick, 187 acres in New Salem, 124 acres in Petersham, and 112 acres in Pelham.

For the purpose of this section, Quabbin's woods roads have been categorized into four types. The following describes these categories and the general maintenance and reconstruction requirements of each.

Type 1: All-Weather Gravel or Asphalt Roads

Road Width: 12 ft. to 24 ft.
Road Surface: Processed gravel or pavement
Drainage: Road drainage system adequate to protect roadway in most climatic conditions (25-year storm).

Type 1 Maintenance Considerations: Type 1 Roads which have a pavement surface must be swept clean of the buildup of organic materials every five years. Gravel roadways must be graded annually with a road grader. Ditches must be cleared and culverts must be cleaned and replaced as necessary. Roadside brush must be mowed yearly.

Example of Type 1 Road: Pavement, Gate 40 road to Dana
Gravel, Gate 20 road to Lily Pond

Type 2: Secondary Gravel Roads

Road Width: 10 ft. to 12 ft.
Road surface: Processed gravel or bank run gravel
Drainage: Road drainage system adequate to protect roadway throughout most of the year. Roads must be closed during the spring mud season.

Type 2 Maintenance considerations: Type 2 Roads must be graded annually with a road grader. Ditches must be cleaned. Culverts must be cleaned and kept free of debris and replaced as necessary. Roadside brush must be mowed a minimum of every three years.

Example of Type 2 Road: Governor's Woods Road From Gate 8

Type 3: Intermittent-use Roadways

Road width: 8 ft. to 12 ft.
Road Surface: Gravel or grass covered.
Drainage: Road Drainage system inadequate for use except when conditions are very dry.

Type 3 Maintenance considerations: Many Type 3 Roads are dead-end access roads not more than 1/2 mile in length. These roads must be mowed every three years to keep them open. Any culverts that are present, particularly at brook crossings, must be inspected and maintained as necessary. Some of these roadways are situated on hillsides with a greater than 10-degree slope. Special consideration must be exercised to protect the vegetative cover and maintain culverts and waterbars on these slopes.

Example of Type 3 Road: Gates 24 and 25 to the intersection of Gate 22 road

Type 4: Forwarder Roads

Road Width: 8 ft. to 12 ft.
Road surface: Vegetative cover, impassable in all seasons except by specialized machinery.

Drainage: Temporary drainage systems may be used. Waterbars used to control erosion on slopes.

Type 4 Maintenance considerations: Type 4 roads are deadend access roads, used only on a frequency of every five to forty years. These roadways are only used during the actual operation of timber sales; when a particular sale is finished, the roadway will be stabilized to prevent overland erosion.

Road reconstruction procedures for Type 1, 2, and 3 roadways (five to ten year cycle):

Culvert replacement: Roadways to be reconstructed will be examined to determine the condition and proper size of all culverts and water-flow structures. Any substandard structures will be replaced or in the case of large culverts and bridges will be referred to MDC Civil Engineering Section for specific action.

Widening of road to category standard: This operation includes the widening of the roadway by removing organic material, the installation of all storm run-offs and ditches, the shaping of the road subgrade for proper crowning and preparing surface for gravel application as necessary.

Basic minimum requirements for a gravel road would be 12" of bank run gravel or 6" minus processed material (material which fits through a 6" screen) and a top coat of a minimum 4" of 1.5" minus processed gravel.

C. WATER QUALITY CONSIDERATIONS ALL ROAD TYPES

In accordance with procedures developed in cooperation with the MDC Environmental Quality Section and published by the MDC Watershed Management Division in the *Erosion and Sediment Control Manual* (Vignaly et al. 1994), a number of mitigation techniques are currently being used during road maintenance and repair work. These mitigations include:

- The use of hay bales or industry standard silt fence whenever culvert, waterbar, or relief ditch work might deposit turbid runoff water into a wetland or watercourse.

- The use of "geotextiles" to stabilize roadbeds where extraordinary amounts of fill might otherwise be needed.

- The use of "conservation mix" grass seed and other fast-growing seed mixtures to stabilize disturbed soil around construction sites.

- The use of waterbars and relief ditches on slopes in excess of 10 degrees for 1,000 feet where storm runoff may cause erosion problems.

D. LARGE CULVERT AND BRIDGE REPLACEMENT

Many large stream culverts and bridges have been identified as either unsafe for vehicle traffic or inadequate for 50-year storm flow. These structures can be a major source of point-source pollution, particularly when breached by a major storm event. The cost of replacing these structures can range from $10,000 to $200,000. With the assistance of the Civil Engineering Section, MDC will choose one structure per year for replacement. This work will be done in late summer to take advantage of low stream flow which will help limit the environmental impact of this work on the stream. The use of innovative culvert designs with built-in spillways or other relief mechanisms may greatly reduce the overall costs of these projects.

E. GENERAL ROAD MAINTENANCE SCHEDULE

The condition of Quabbin's gravel roads has been steadily improving over the past decade. During the 1980's, MDC foresters included the cost of upgrading access to forest management sites in the timber sale contracts. The addition of the watershed maintenance personnel in 1987 has greatly added to the miles of roads which have been improved. The next decade will focus on "fine-tuning" the access system, gradually moving from a reconstruction to a maintenance orientation.

The amount of maintenance needed on each type of roadway is hard to predict precisely. It is clear that not all the work needed on all roadways will occur within the scope of this Management Plan. The work needed to keep all major roads open throughout the year also is largely dependent on weather. Major storm events affect roadways as trees or limbs fall into the roadway making them impassable. Crews are dispatched after each major storm event to clear roads of fallen debris. Washouts due to culvert failure or clogged drainage ditches occur after major storms.

It is the MDC's intention to limit washouts by replacing under-sized culverts with structures that will meet standards for a 50-year flood. These culverts and ditches will be kept open and clear of all restrictions in order to prevent the backup of storm runoff and the resulting washout. All beaver control structures in use on the watershed will be designed to accommodate the full specified flow of water through the culvert.

Road Grading: The grading of Type 1 and 2 roads is a function which should occur on an annual basis. This will be accomplished by the dedication of one road grader to MDC Quabbin lands. Concurrent with the grading of roads should be the clearing of rocks from roadways, clearing of culverts and removing of hazardous roadside trees.

Roadside Mowing: The mowing of roadsides will be done on a annual basis. The Quabbin Section purchased a roadside boom mower in 1992 for the purpose of maintaining all Quabbin Section roadsides. The cutting of roadsides will be undertaken whenever staffing is available from May through November.

Gravel Processing: Processed material will be used throughout the watershed to improve road surfaces of the existing gravel roads. Each year MDC will contract the processing of gravel at designated sites. New sites for gravel removal will be explored when the proximity to job sites of existing gravel supplies makes the cost of trucking the material prohibitive.

APPENDIX IX. REMOVAL OF NON-RENEWABLE RESOURCES

The Division of Watershed Management has care of and control over approximately 120,000 acres of land and water in four watersheds. Within these holdings are vast non-renewable resources including soil, gravel, sand, clay, boulders, stone and minerals. The following policy will guide the activities of the Division with regard to the management and use of these non-renewable resources.

A. EXISTING REGULATIONS

Chapter 737, Acts of 1972, which deals specifically with the Quabbin and Ware River Watersheds, states:

"No person shall take or remove and no town within the District shall authorize the taking or removal of sand, gravel, dirt, or soil, nor any other mineral, from or within the district, except only that the Commission may take such of these materials as are required for Commission use within the district and may allow such use of these materials as may be required pursuant to Section Five." (Section Five refers to existing agreements with towns made prior to 1972; the District refers to the Commission holdings in Ware River watershed as of 1965 and its holdings at Quabbin watershed inside Routes 9, 32, 32A, 122 and 202.)

The following towns within Quabbin, Ware River, and Wachusett watersheds have earth removal bylaws of some type: Belchertown, Ware, Pelham, Templeton, Phillipston, Holden, Boylston, and Sterling. Boylston also has a bylaw relating to erosion and sedimentation.

Chapter 240, Acts of 1938, Section 4 gives the towns of Petersham and New Salem the right to take gravel for municipal purposes from areas under the care and control of the Commission in their respective towns at no cost.

B. PROHIBITION OF REMOVAL OF THE NON-RENEWABLE RESOURCES FOR NON-MDC PURPOSES

The Division will not allow the disturbance or removal of any non-renewable resources from the lands and waters under its care and control, except for MDC management purposes discussed below. Any such activities shall be pursued with legal action. The only exception shall be to allow the towns of Petersham and New Salem to remove gravel according to Chapter 240, Acts of 1938. Petersham and New Salem must contact the appropriate forester indicating the location, timing, and volume of any anticipated removals. All such removals shall occur under the direction of the Division's foresters. Petersham and New Salem will be responsible for securing all other necessary permits and approvals outside of Commission jurisdiction. These gravel removals will also be reviewed by other Division staff as outlined in section C. below.

C. POLICY FOR THE LIMITED REMOVAL OF NON-RENEWABLE RESOURCES FOR MDC MANAGEMENT PURPOSES

It is necessary for the Division to use certain amounts of non-renewable resources in carrying out its mandate to protect the water and environment under its care and control. These materials include: gravel, sand, and stone for the maintenance and construction of forest access roads (necessary for fire protection, police patrols, research, and forest and wildlife management) and boulders used for blocking motorized access to Division lands. The above materials are available both above and below the high water mark of the Division's reservoirs.

The Division foresters shall include in this Plan long-range (twenty-five years) needs for forest roads and access protection on all Division holdings. Forest roads shall include the first three classes described in Appendix VI; Types 1, 2, and 3. Written standards for the maintenance and construction of the three road classes will be included as well as the location of all gravel removal areas necessary to maintain the above forest road system for the twenty-five year planning period.

In the selection of gravel removal areas, the Forester will give priority to gravel from the following sources:

- existing gravel pits,
- below the high water mark of the Quabbin and Wachusett Reservoirs when removal can proceed without water quality impacts,
- purchase of gravel from private lands where this removal will have less of an impact upon the water and environment under the care and control of the Division than removals from Commission lands (for example lands off of

the watershed),

- removals from the remains of aqueduct shaft excavation piles.

Where no appropriate gravel supplies are located in the above areas, the forester shall select a site within the Division holdings which will cause the minimum impacts possible to the water, natural, cultural, and scenic resources of the Division.

Before a new gravel removal location is approved, the following procedure will be followed:

1. Development of a plan showing the location to be affected, time sequence of removals and reclamation procedures to be employed,

2. Consultation with Division Section Superintendents, Environmental Quality and Wildlife staff and MDC Chief Archaeologist to determine that no significant impacts will occur to the water quality or wildlife and cultural resources,

3. Consultation with and completion of all necessary approvals from the Department of Environmental Protection, Department of Fisheries and Wildlife, and Environmental Law Enforcement (for information on both fisheries and rare species impacts), the local town Conservation Commission or other local bodies, and any other governmental entity with jurisdiction over the chosen site.

4. Final approval from Director of Natural Resources and the Division Director.

The removal of individual boulders shall be allowed for the purpose of blocking access to Commission lands only. The location and removal of such boulders shall be approved and supervised by the Division foresters. The above procedure (1-4) will be followed when boulder removal is extensive or may in any way impact significantly upon natural or cultural resources.

APPENDIX X. LOT REVIEWS FOR SILVICULTURAL TREATMENTS

Lot Review forms are submitted by MDC Foresters each January, to notify appropriate MDC personnel of silvicultural work proposed for the next fiscal year. Each form includes a detailed description of the boundary, overstory and understory, forest type, topography, soils, and presence of wetlands in each proposed lot. The presence of Cultural Resources, wildlife habitats, and rare plant or animal species is also recorded. Management information includes current regeneration status and the silvicultural goal of the proposed treatment.

These forms are sent through the Natural Resource Specialist responsible for forest management, for review and comment by the MDC Chief Archaeologist, the Natural Resource Specialist responsible for wildlife management, the MDC rare and endangered plant specialist, the Environmental Quality staff, and the supervisor responsible for required forest road work.

A notebook containing the post-review forms for approved lots is available in the Quabbin Visitors' Center, and contains a map for each lot. Descriptions and maps of the ninety-four Compartments comprising Quabbin's five Management Blocks (Hardwick, New Salem, Pelham, Petersham, Prescott) are on file at the Natural Resources office.

APPENDIX XI. GREEN CERTIFICATION AT QUABBIN

The article below summarizes the Green Certification process at Quabbin, which culminated in the achievement of "Green Certified" status from the Smart Wood program of the Rainforest Alliance, regionally affiliated with the National Wildlife Federation. Quabbin's certification was announced in June 1997, and was the first such certification of publicly-owned forest in North America. This article appeared in the May/June 1997 "Woodland Steward," a publication of the Massachusetts Forestry Association, P.O. Box 1096, Belchertown, MA 01007-1096, Tel:413-323-7326.

Quabbin *Green*: The Certification of Public Land Forestry

By Thom Kyker-Snowman

Quabbin - "meeting of many waters"; "the accidental wilderness"; source of drinking water for eastern Massachusetts and Mecca for "westerners" seeking solitude (and fish); model watershed management and source of endless controversy – has recently added a new distinction to its repertoire: the first public land in the country to earn "Green Certification" for its forest management practices.

What is Green certification? The concept originated as a way to improve harvesting practices in the tropics, but has expanded to provide independent assessment of forestry practices throughout the world. Similar to the "organic" label for food, the "Green" label on forest products is meant to assure consumers that long-term sustainable practices brought the labeled wood to market, rather than near-sighted greed or a careless desire for maximum short-term production. Green certification will grow or die on consumer demand for wood products from known sources. It will probably grow, and in direct relation to increasing public concern for our collective treatment of forests throughout the world. One recent survey showed that 67% of a middle to upper income group had made purchasing decisions based on the desire to boycott products associated with undesirable environmental impacts.

Quabbin forestry has set an example in Massachusetts and throughout New England for sustainable forest practices since the first MDC forest management plan, filed in the early 1960's. The practice of forestry on Quabbin is guided by principles of watershed protection, not the need to feed a mill. While 3-5 million board feet are harvested annually from the 45,000 acres under active management, no specific revenue goals have ever driven Quabbin silviculture. This fact has allowed careful, sustainable practices to prevail for almost four decades. Water yield has been largely supplanted by water quality as the guiding standard for timber harvesting, but MDC's constraints on the environmental impact of harvesting have consistently exceeded the average (see sidebar). In fact, the Quabbin Land Management Plan for 1995-2004 goes beyond the typical requirements for Best Management Practices to protect water *from* harvesting, by stating that harvesting is *required* in order to maintain the resilience of the forest cover that protects the water. This long-term resilience is a component of the Quabbin Watershed Protection Plan, which maintains MDC's waiver from EPA-required filtration of this drinking water source for 2.5 million people, nearly 40% of the Commonwealth.

So why would this public agency seek Green certification? That is, if market price is secondary to the objectives of management, and the managing agency already adheres to the highest standards of timber harvesting in the industry, what are the possible gains from seeking certification? To begin with, the MDC felt that a third party audit of the agency's claims of sustainable forestry practices would provide important assurances to the increasingly concerned public. Furthermore, while proud of the logging standards on Quabbin properties, MDC staff felt that an independent review might provide suggestions for further improvement of those standards. Finally, the MDC hoped that premiums associated with a developed market for "Green" forest products might provide incentives for the owners of the 28,000 acres of private forestland on the Quabbin watershed to improve their management practices. With these possibilities in mind, MDC issued a Request for Proposals to assess Quabbin forestry for certification, in January of 1995.

There are just two organizations in North America (just four worldwide) that are accredited to grant Green certification. This accreditation comes from the Forest Stewardship Council, a non-profit consortium of environmental groups and forest managers based in Mexico (this is *not* the US Forest Stewardship program, which cost-shares forest practices on private lands). The two F.S.C.- accredited N.A. certifiers are Scientific Certification Systems, a for-profit company based in California and the Smart Wood program, a non-profit affiliate of the Rainforest Alliance and the National Wildlife Federation, with a Northeast regional office in Vermont. Both S.C.A. and Smart Wood submitted bids on the certification assessment at Quabbin, and the MDC ultimately selected the Smart Wood program based on a combination of the fit of their proposal with MDC objectives, and cost.

The full details of the certification process are complex and custom-tailored to the individual property. Briefly, they include:

- a *scoping process* – which establishes the major assessment issues and determines the sufficiency of available data on the property

- the *field assessment* – during which a team of forestry, ecology, and socio-economic experts performs a highly detailed investigation of the property, its management, and the surrounding community and markets
- the delivery of an *assessment report*
- issuance of a *certification decision*
- *public disclosure* statement

In assessments of large private business ownerships, the public disclosure statement provides detailed information on the assessment while protecting proprietary information. For public lands such as the Quabbin, where there is no such thing as proprietary information, the public statement provides a full disclosure of all aspects of the assessment.

The field assessment team for the Quabbin included Alan Calfee, a forester and the regional coordinator for Smart Wood; Tom Wessels, a forest ecologist and instructor at Antioch New England College; Richard Donovan, a harvesting specialist from the Rainforest Alliance; and Dr. Paul Barten, a forest hydrologist and professor at Yale University. This team was brought together with MDC staff involved with forest management for a period of about two weeks in the field. Thirty-five years of management plans, forest inventory data, and timber harvesting records were painstakingly scrutinized. A stratified sample of current, past, and proposed timber harvesting lots was inspected for impacts on residual resources, the productivity of the operation, and the achievement of desired silvicultural effects. The field assessment considered overall threats to forest security and health, long-term sustainability of the management approach, technical quality of forest harvesting, landscape level impacts, optimization of forest potential, effects on local communities, and economic viability of the forest operations.

It was the first time any outside group had looked so intensively and objectively at Quabbin's management, and the first time Smart Wood had assessed a large, public holding in the U.S. The issue of economic viability was unusual at Quabbin, in that the primary "product" of the operations is drinking water. While Quabbin's highly restrictive management practices may not generate the same profit margin as a private forest corporation might expect from its lands, much of the cost to run Quabbin must be credited toward the protection of drinking water and the cost of doing business for the public sector. Because Quabbin is "everyone's business", more staff time and expense than a private company could afford is spent working with the wide range of publics who use and care about this watershed forest.

In addition to the time spent directly with Quabbin staff and on Quabbin land, the Smart

Wood team also interviewed a large cross-section of stakeholders affected directly or indirectly by Quabbin's forest management practices. These included logging contractors, local town assessors and other officials, representatives of environmental organizations and other state environmental agencies, local consulting foresters, and just plain neighbors. The assessment process and draft findings were presented to Quabbin's Science and Technical Advisory Committee, and a public presentation of the process was delivered following a 600 piece mailing to an even wider spectrum of potential stakeholders.

Detailed results of the certification assessment are available in a final report from Smart Wood. This report contains scores and comments on nearly 100 criteria. Scoring on applicable regional criteria can range from "extremely weak performance" (a score of 1) to "state of the art" (a score of 5). Quabbin practices were rated 5 ("state of the art") for 50% of the assessed criteria, and most other areas were scored 4 ("well above the norm for the region"). Just two criteria were rated 3 (certifiable, above the norm for the region). For practices that are state of the art, the assessment only makes non-binding recommendations to improve or sustain current conditions. For others, there are "conditions" attached, which must be met within a short time following certification in order to maintain that certification. An example at Quabbin includes the requirement that future harvests that involve chipping must be required contractually to leave behind sufficient coarse woody debris to meet biological requirements of the site (in short, chipping operations were too clean at Quabbin). Another condition requires that all forest type maps at Quabbin be updated within three years of the original certification date. There is a requirement to investigate the value of establishing landscape "links" between some of the isolated areas on Quabbin which have been removed from management for various reasons (too wet, too steep, etc.). A related condition requires the MDC to work to identify and protect unusual forest types, an example of which is the scattered small stands of extremely old tupelo around Quabbin.

It seems clear that certification of a large Massachusetts landholding will attract new markets for Quabbin's forest products. There are at least two companies already inquiring about the availability of "green" wood, one of which is competing in the race to produce chlorine-free pulp from certified sources of wood, while the other is working to fill the niche for upper grades of "green certified" hardwood lumber. For such markets to work, certifying groups will have to be involved in the entire chain of custody from the woods to the final product. It is doubtful that any single mill could afford to buy exclusively "green" wood, so that tracking that wood from the mill yard through to the final product is problematic from the start. Without such tracking, the premiums at the retail end might never find the way back to the "green certified" landowner.

With these kinds of risks, what financial incentive is there for the many small, private landowners on the Quabbin watershed to apply to be certified? A somewhat less tangible incentive is the desire simply to distinguish one's management, no matter how small the acreage, from less thoughtful practices. How many of you who own and carefully manage woodland are frustrated by the naïve stereotype that anyone who cuts timber to sustain their land falls in the same bin as the worst timber beast? The desire for this type of distinction has brought many landowners into the Tree Farm and Forest Stewardship programs. Small may be beautiful, but the more difficult question to answer is how much it will cost the smallholder to become certified. For large holdings such as the Quabbin, the expense of the detailed certification process might average out to a dollar or two per acre, but many of the costs are fixed, so that the per acre charge rises dramatically as the total acreage shrinks. Smart Wood is currently working with a model that might solve this problem. A consulting forester's management on a collection of individual parcels is certified, allowing him to broker certified wood products from all these clients without any of them requiring individual certification. Certifiers admit that small landowners, which are absolutely the norm in New England, are the most difficult nut to crack, but the consultant model just might be the tool that works.

If you want to learn more about the Green Certification process, contact me for a copy of the Quabbin report, or write to either Alan Calfee, Regional Coordinator – Smart Wood Program, Northeast Natural Resource Center, P.O. Box 1876, Manchester Center, VT 05255, or Debbie Hammel, Directory of Forestry Programs, Scientific Certification Systems, The Ordway Building, One Kaiser Plaza, Suite 901, Oakland, CA 94612. I would also recommend reading Certification of Forest Products: Issues and Perspectives, 1996, Island Press, ISBN 1-55963-494-4.

LITERATURE CITED

Aber, J.D. 1993. Modification of nitrogen cycling at the regional scale: the subtle effects of atmospheric deposition. In McDonnell, M.J. and S.T.A. Pickett, editors. Humans as Components of Ecosystems: the Ecology of Subtle Human Effects and Populated Areas. 163-174. New York: Springer-Verlag.

Aber, J.D. 1992. Nitrogen cycling and nitrogen saturation in temperate forest ecosystems. Tree. 7(7):220-224.

Aber, J.D., D.B. Botkin, and J.M. Melillo. 1978. Predicting the effects of different harvesting regimes on forest floor dynamics in northern hardwoods. Can. J. For. Res. 8: 306-315.

Aber, J.D., J.M. Melillo and C.A. McClaugherty. 1989. Predicting long-term patterns of mass loss, nitrogen dynamics, and soil organic matter formation from initial fine litter, chemistry in temperate forest ecosystems. Canadian Journal of Botany. 68:2201-2208.

Aber, J.D., J.M. Melillo and K.J. Nadelhoffer, J. Pastor and R.D. Boone. 1991. Factors controlling nitrogen cycling and nitrogen saturation in northern temperate forest ecosystems. Ecological Applications. 1(3): 303-315.

Absalom, S. 1988. Comparison of avian community structure and habitat structure in mature versus old-growth northern hardwoods forests. University of Massachusetts: Master's thesis.

Adams, D.L. and G.W. Barrett. 1976. Stress effects on bird-species diversity within mature forest ecosystems. Amer. Midl. Natur. 96:179-194.

Agee J.K. and D.R. Johnson. 1988. Ecosystem management for parks and wilderness. University of Washington Press.

Agren, G.I. and E. Bosatta. 1988. Nitrogen saturation of terrestrial ecosystems. Environ. Pollution. 54:185-197.

Ambuel, B. and S.A. Temple. 1983. Area-dependent changes in the bird communities and vegetation of southern Wisconsin forests. Ecology. 64(5):1057-1068.

American Forest Council. 1986. Your water - a forest product. Washington, D.C.: GreenAmerica, American Forest Council.

Anderson, J.F. and H.K. Kaya, editors. 1976. Perspectives in Forest Entomology. New Haven: Conn Agricultural Exp. Station.

Anderson, S.H. and H.H. Shugart Jr. 1974. Habitat selection of breeding birds in an east Tennessee deciduous forest. Ecology. 55:824-837.

Apple, L.L. nd. Riparian habitat restoration in cold desert, gully-cut stream systems: an innovative, cost effective, ecological approach. Rock Springs, Wyoming:U.S. Bureau of Land Management. Unpublished manuscript.

Arben, E. (editor). 1910. The Travels and Works of Captain John Smith, President of Virginia and Admiral of New England 1580-1631. Edinborough: John Grant.

Arbogast, C., Jr. 1957. Marking guides for northern hardwoods under the selection system. USDA Forest Service: Lake States Forest Experiment Station Paper 56.

Art, H.W. and D.P. Dethier. 1986. Influence of vegetative succession on soil chemistry of the Berkshires. University of Massachusetts, Amherst: Water Resources Research Center Publication, Project No. G912-05.

Austin, P., R. Bishop, D. Chandler, P. Deslauriers and M. Hopkinson. 1992. 1992 Water quality report: Quabbin Resevoir and Ware River watersheds. Commonwealth of Massachusetts: MDC, Division of Watershed Management.

Austin, P., R. Bishop, D. Chandler, P. Deslauriers and M. Hopkinson. 1990. 1990 Water quality report: Quabbin Resevoir and Ware River watersheds. Commonwealth of Massachusetts: MDC, Division of Watershed Management.

Baker, John H. 1984. Sulfate retention by forest soils of central New England. University of Massachusetts: Water Resources Research Center Publication No. 151.

Balda, R.P. 1975. Vegetative structure and breeding bird diversity. In D.R. Smith, editor.

Proc. symp. on manage. of forest and range Habitats for nongame birds. 59-80. U.S. Forest Service: Gen. Tech. Rep. WO-1.

Barnes, W.J. and E. Dibble. 1988. The effects of beaver riverbank forest succession. Can. J. Bot. 66:40-44.

Batchelder, G.L., R.F. Yuretich and W.C. Leonard. 1983. Hydrogeochemical cycling in a watershed-groundwater system: Fort River and Cadwell Creek, Massachusetts. University of Massachusetts: Water Resources Research Center Publication No.145.

Baxter, R.M. 1977. Environmental effects of dams and impoundments. Ann. Rev. Ecol. Syst. 8:255-283.

Beggar, H.P. (editor). 1922-1936. The Works of Samuel de Champlain (1626). 6 volumes. Toronto: The Champlain Society.

Bennett, S.H., J.W. Gibbons and J. Glanville. 1980. Terrestrial activity, abundance and diversity of amphibians in differently managed forest types. Amer. Midl. Natur. 103(2):412-416.

Bennett, A.L. 1962. Industrial forestry and wildlife - the Northeast. J. For. 60(1):18-20.

Benton, C., F. Khan, P. Monaghan, W.N. Richards and C.B. Shedden. 1983. the contamination of a major water supply by gulls (*Larus* sp.): a study of the problem and remedial action taken. Water Res. 17:789-798.

Berry, K.H. 1986. Introduction: development, testing and application of wildlife habitat models. In J. Verner, M.L. Morrison and C.J. Ralph, editors. Wildlife 2000: Modeling habitat relationships of terrestrial vertebrates. 3-4. University of Wisconsin Press.

Berryman, A.A. 1986. Forest Insects: Principles and Practice of Population Management. New York & London: Plenum press.

Block, W.M., L.A. Breman and R.J. Gutierrez. 1986. The use of guilds and guild-indicator species for assessing habitat suitability. In J. Verner, M.L. Morrison and C.J. Ralph, editors. Wildlife 2000: Modeling habitat relationships of terrestrial vertebrates. 109-113. University of Wisconsin Press.

Blockstein, D.E. 1990. Toward a federal plan for biological diversity. J. For.:15-19.

Bormann, F.H. and G.E. Likens. 1979a. Catastrophic disturbance and the steady state in Northern Hardwood Forests. American Scientist 67:660-669.

Bormann, F.H. and G.E. Likens. 1979b. Pattern and process in a forested ecosystem. New York: Springer-Verlag.

Bormann, F.H., G.E. Likens, and J.S. Eaton. 1969. Biotic regulation of particulate and solution losses from a forest ecosystem. Bioscience 19 (July): 600-610.

Bormann, F.H., G.E. Likens, D.W. Fisher, R.S. Pierce. 1968. Nutrient loss accelerated by clear-cutting of a forest. Ecosystem Science. February: 882-884.

Bormann, F.H., G.E. Likens, T.G. Siccama, R.S. Pierce, and J.S. Eaton. 1974. The export of nutrients and recovery of stable conditions following deforestation at Hubbard Brook. Ecological Monographs 44: 255-277.

Botkin, D.B. 1990. Discordant harmonies. New York: Oxford Univ. Press.

Brach, John. 1991. Protecting water quality in urban areas. In: Best Management Practices for Minnesota. Unpublished.

Bradshaw, F.J. 1992. Quantifying edge effect and patch size for multiple-use silviculture - a discussion paper. For. Ecol. Manage. 48:249-264.

Branvold, D.K., C.J. Popp and J.A. Brierly. 1976. Waterfowl effects on water quality: II. Chemical and physical parameters. J. Wat. Poll. Cont. Fed. 48:680-687.

Braun, E.L. 1950. Deciduous forests of eastern North America. NewYork: The Free Press.

Brayton, D.S. 1984. The beaver and the stream. J. Soil & Water Conserv. 39:108-109.

Briggs, J.C. and J.F. Ficke. 1977. Quality of rivers of the United States, 1975 water year - based on natural stream quality accounting network (NASQUAN). U.S. Geological Survey Open-file Rep. 78-200.

Brittingham, M.C. 1989. Effects of timber management practices on forest interior birds. In J.C. Finley and M.C. Brittingham, editors. Timber management and its effects on wildlife. Proc. 1989 Penn. State For. Res. Issues Conference. 163-170. Pennsylvania State University.

Brittingham, M.C. and S.A. Temple. 1983. Have cowbirds caused forest songbirds to decline? BioScience 33:31-35.

Bromley, S.W. 1935. The original forest types of southern New England. Ecol. Monographs Vol 5(1): 63-89.

Brown, G.W. 1976. Forestry and water quality. Corvallis: Oregon State University Book Stores, Litho-USA.

Brown, K.A., P.H. Freer-Smith, G.D. Howells, R.A. Skeffington and R.B. Wilson. 1988. Report on discussions at the workshop on excess nitrogen deposition, September 1987. Environmental Pollution. 54: 285-295.

Brown, L.H. 1972. Logging and water quality in the Pacific Northwest. In National Symposium on Watersheds in Transition. Amer Water Resources Association No. 14.

Buhlmann, K.A., C.A. Pague, J.C. Mitchell and R.B. Glasgow. 1988. Forestry operations and terrestrial salamanders: techniques in a study of the Cowknob Salamander, *Plethodon punctatus*. In Szaro et al., editors. Management of Amphibians, Reptiles and Small Mammals in North America. 38-44. USDA Forest Service: Gen. Tech. Rep. RM-166.

Burley, F.W. 1988. Monitoring biological diversity for setting priorities in conservation. In E.O. Wilson, editor. Biodiversity. Chapt. 26. Nat'l Acad. Press.

Burns, R.G. and J.D. Hewlett. 1983. A decision model to predict sediment yield from forest practices. Water Resources Bulletin 19(1):9-14.

Bushman, E.S. and G.D. Therres. 1988. Habitat management guidelines for forest interior breeding birds of coastal Maryland. Md. Dept. Nat. Res.: Wildlf. Tech. Publ. 88-1.

Buzzell, G. 1991. 1990 Wachusett storm salvage study. Commonwealth of Massachusetts: MDC Publication.

Camp, Dresser, and McKee, Inc. 1995. Wachusett Reservoir water quality studies: interim assessment. Unpublished MWRA Report.

Carlson, J. 1994. Effects of a simulated hurricane on downed woody fuel loading in a central Massachusetts hardwood stand. Harvard University: Abstracts of 5th Annual Harvard Forest Ecology Symposium.

Carlton, M. 1990. Literature review: water quality implications of converting forested watersheds to principally herbaceous cover - implications to the Quabbin watershed. Commonwealth of Massachusetts: MDC Publication.

Carroll, Charles F. 1973. The Timber Economy of Puritan New England. Providence, Rhode Island: Brown University Press.

Caughley, G. 1981. Overpopulation. In Jewell and Holt (editors). Problems in management of locally abundant wild mammals. 9-19. New York: Academic Press.

Chadwick, D.H. nd. The biodiversity challenge. Defenders magazine special report.

Chadwick, N.L., D.R. Progulske and J.T. Finn. 1986. Effects of fuelwood cutting on birds in southern New England. J. Wildlf. Manage. 50:398-405.

Chambers, R.E. 1989. Assessment of forest habitats for wildlife. In J.C. Finley and M.C. Brittingham, editors. Timber management and its effects on wildlife. Proc. 1989 Penn. State For. Res. Issues Conference. 55-61. Pennsylvania State University.

Cline, A.C. and S.H. Spurr. 1942. The virgin upland forest of central New England: a study of old growth stands in the Pisgah Mountain section of southwestern New Hampshire. Harvard Forest Bulletin No 21.

Cobourn, J. 1989. Is cumulative watershed effects analysis coming of age? J. Soil and Water Conservation, July-August 1989: 267-270.

Commonwealth of Massachusetts, Metropolitan District Commission. 1995. Quabbin Watershed: MDC Land Management Plan 1995 - 2004. MDC publication.

Commonwealth of Massachusetts, Department of Environmental Protection and

Metropolitan District Commission. 1994. Gates brook stormwater study (Wachusett Reservoir): 1990 through 1991. DEP/MDC report.

Commonwealth of Massachusetts, Metropolitan District Commission and MWRA. 1991. Watershed protection plan: Quabbin Reservoir and Ware River watersheds. Prepared by Rizzo Assoc. and CH2M Hill.

Commonwealth of Massachusetts, Department of Environmental Protection and Metropolitan District Commission. 1990. Quabbin tributaries: water quality data report, 1989-90. Report available from either agency.

Commonwealth of Massachusetts, Metropolitan District Commission. 1988. Water Quality Report, 1988, Quabbin Reservoir and Wachusett Reservoir: watershed monitoring results. MDC report.

Commonwealth of Pennsylvania, Department of Environmental Resources, Office of Resources Management, Bureau of Forestry. 1985a. Forest resources plan, the report, Tiadaghton State Forest: 1985-1999.

Commonwealth of Pennsylvania, Department of Environmental Resources, Office of Resources Management, Bureau of Forestry. 1985b. Forest resources plan, timber management section, Tiadaghton State Forest: 1985-1999.

Commonwealth of Pennsylvania, Department of Environmental Resources, Office of Resources Management, Bureau of Forestry. 1985c. Forest resources plan, minerals management section, Tiadaghton State Forest: 1985-1999.

Commonwealth of Pennsylvania, Department of Environmental Resources, Office of Resources Management, Bureau of Forestry. 1985d. Forest resources plan, fauna and flora management section, Tiadaghton State Forest: 1985-1999.

Conner, R.N. and C.S. Adkinson. 1975. Effects of clearcutting on the diversity of breeding birds. J. For. 73:781-785.

Corbett, E.S. and W. Spencer. 1975. Effects of management practices on water quality and quantity: Baltimore, Maryland municipal watersheds. In: Municipal Watershed Management Symposium Proceedings: 25-31. USDA Forest Service General Technical

Report NE-13.

Coulson, R.N. and J.A. Witter. 1984. Forest Entomology: Ecology and Management. New York: John Wiley & Sons, Inc.

Craun, G.F. 1984. Waterborne outbreaks of giardiasis, current status. In Erlandsen and Meyer editors. Giardia and giardiasis. 243-261. New York: Plenum Press.

Crawford, H.S. 1976. Relationships between forest cuttings and understory vegetation: an overview of eastern hardwood stands. USDA Forest Service: Res. Paper NE-349.

Crawford, H.S., R.G. Hopper and R.W. Titterington. 1981. Songbird population response to silvicultural practices in central Appalachian hardwoods. J. Wildlf. Manage. 45:680-692.

Crawford, H.S., J.B. Whelan, R.T. Harlow and J.E. Skeen. 1975. Deer range potential in selective and clearcut oak-pine stands in southwest Virginia. USDA Forest Service: Res. Paper SE-134.

Crocker-Bedford, D.C. 1990. Goshawk reproduction and forest management. Wildl. Soc. Bull. 18: 262-269.

Cronon, W. 1983. Changes in the Land: Indians, Colonists, and the Ecology of New England. New York: Hill and Wang.

Currier, J.B., L.E. Siverts, and R.C. Maloney. 1979. An approach to water resources evaluation of non-point sources from silvicultural activities - a procedural handbook. In Best Management Practices for Agriculture and Silviculture: Proceedings of the 1978 Cornell Agricultural Waste Management Conference. Michigan: Ann Arbor Science Publishers Inc.

Davies, R.B. and C.P. Hibler. 1976. Animal reservoirs and cross-species transmission of Giardia. In Jakubowski and Hoff, editors. Waterborne transmission of giardiasis. 104-126. U.S. EPA - 600/9-79-001.

Day, G.M. 1953. The Indian as an ecological factor. Ecology. 34(2): 329-347.

deCalesta, D.S. 1989. Even-aged management and wildlife populations. In J.C. Finley and M.C. Brittingham, editors. Timber management and its effects on wildlife. Proc. 1989 Penn. State For. Res. Issues Conference. 210-224. Pennsylvania State University.

DeGraaf. R.M. 1982. Breeding bird assemblages in New England northern hardwoods. Proc. Symp. on Impacts of Timber Management Practices on Non-game Birds in Vermont. 5-22. Johnson College.

DeGraaf, R.M. and W.M. Healy. 1989. Is forest fragmentation a management issue in the northeast? USDA Forest Service: Gen. Tech. Rep. NE-140.

DeGraaf, R.M., W.M. Healy and R.T. Brooks. 1991. Effects of thinning and deer browsing on breeding birds in New England oak woodlands. For. Ecol. Manage. 41:179-191.

DeGraaf, R.M. and D.A. Richard. 1987. Forest wildlife of Massachusetts: cover type, size class and special habitat relationships. University of Massachusetts: Coop. Ext. Serv. Publ. C-182.

Diesch, S.L. 1970. Disease transmission of water-borne organisms of animal origin. In T.L. Willrich and G.E. Smith, editors. Agricultural practices and water quality. 269-285. Iowa State Univ. Press.

Dobson, J.E., R.M. Rush and R.W. Peplies. 1990. Annals of the Association of American Geographers. 80(3): 343-361.

Douglass, J.E. 1983. The potential for water yield augmentation from forest management in the eastern United States. Water Res. Bull. 19(3):351-358.

Douglass, J.E. and W.T. Swank. 1975. Effects of management practices on water quality and quantity: Coweeta Hydrologic Laboratory, North Carolina. In Municipal Watershed Management Symposium Proceedings. USDA Forest Service. General Technical Report NE-13: 1-12.

Douglass, J.E. and W.T. Swank. 1972. Streamflow modification through management of eastern forests. USDA Forest Service: Research Paper SE-94.

Driscoll, C.T., N.M. Johnson, G.E. Likens and M.C. Feller. 1988. Effects of acidic deposition on the chemistry of headwater streams: a comparison between Hubbard Brook, New Hampshire and Jamieson Creek, British Columbia. Water Resources Res. 24(2): 195-20.

Driscoll, C.T., G.E. Likens, L.O. Hedin, J. S. Eaton and F.H. Bormann. 1989. Changes in the chemistry of surface waters: twenty-five year results at the Hubbard Brook Experimental Forest, NH. Environ. Sci. Technol. 23:(2)137-143.

Dubuc, L.J., W.B. Krohn and R.B. Owen, Jr. 1990. Predicting occurrence of river otters by habitat on Mount Desert Island, Maine. J. Wildlf. Manage. 54(4):594-599.

Dunne, T. and L.B. Leopold. 1978. Water in Environmental Planning. New York: W.H. Freeman and Company.

Dyrness, C.T. 1965. Erodibility and erosion potential of forest watersheds. In W.E. Sopper and H.W. Lull, editors. Forest Hydrology: Proceedings of a National Science Foundation Advanced Science Seminar at Pennsylvania State University. 559-611. London: Pergamon Press .

Erlandsen, S.L. and W. J. Bemrick. 1988. Waterborne giardiasis: sources of Giardia cysts and evidence pertaining to their implication in human infection. In P.M. Wallis and B.R. Hammond, editors. Advances in Giardia research. 227-236. Alberta: Univ. Calgary Press.

Eschner, A.R. 1978. Long term observations and analyses of the hydrology of small relatively natural watersheds in the Adirondack Mountains. Reprinted from: 1. Tagungsbericht Forschung in mitteleuropaischen Nationalparken. Schriftenreihe des Bayerischen Staatsministeriums fur Ernahrung, Landwirtschaft und Forsten. Grafenau 25-27 Mai 1978.

Eschner, A.R. and D.L. Mader. 1975. Management implications of other hydrologic research in the northeast. In Municipal Watershed Management Symposium Proceedings. USDA Forest Service: Gen Tech Rep NE-13.

Eschner, A.R. and J.H. Patric. 1982. Debris avalanches in eastern upland forests. J. Forestry 80(6): 343-346.

Eschner, A.R. and D.R. Satterlund. 1965. Forest protection and streamflow from an Adirondack watershed. Wat. Res. Res. 2(4):765-783.

Fed. Register. 1987. 52(212):42178. Nov. 3.

Federer, C.A. and D. Lash. 1978. Brook: a hydrologic simulation model for eastern forests. Water Resource Research Center, University of New Hampshire, Durham: Research Report Number 19.

Fennell, H., D.B. James and J. Morris. 1974. Pollution of a storage reservoir by roosting gulls. Wat. Treat. Exam. 23:5-24.

Forman, R.T.T. and M. Godron. 1986. Landscape ecology. New York: Wiley& Sons.

Foster, D.R. 1992a. Land-use history (1730-1990) and vegetation dynamics in central New England, USA. Journal of Ecology. 80:753-772.

Foster, D.R. 1992b. Land-use history and forest transformations in Central New England. In S. Pickett and M. McDonnell (eds.) Human Impacts on the Environment. New York: Springer-Verlag.

Foster, D.R. 1988. Disturbance history, community organization and vegetation dynamics of the old-growth Pisgah Forest, south-western New Hampshire, U.S.A. Journal of Ecology 76: 105-134.

Foster, D.R. and E.R. Boose. 1992. Patterns of forest damage resulting from catastrophic wind in central New England, U.S.A. Journal of Ecology 80:79-98.

Foster, D.R. and D.R. Smith (editors). 1993. Harvard University: Abstracts of 4th Annual Harvard Forest Ecology Symposium.

Foster, D.R. and T.M. Zebryk. 1993. Long-term vegetation dynamics and disturbance history of a Tsuga-dominated forest in central New England. Ecology. 74:982-998.

Foster, D.R., T. Zebryk, P. Schoonmaker and A. Lezberg. 1992. Post-settlement history of human landuse and vegetation dynamics of a Tsuga canadensis (hemlock) woodlot in central New England. Journal of Ecology 80:773-786.

Foster, N.W., J.A. Nicolson and P.W. Hazlett. 1989. Temporal variation in nitrate and nutrient cations in drainage waters from a deciduous forest. Journal of Environmental Quality. 18: 238-244.

Frank, R.M., T.L. Stone and H.S. Crawford. nd. US Forest Service (Orono, ME): unpublished manuscript.

Frankel, O.H. and M.E. Soule. 1981. Conservation and evolution. Cambridge University Press.

Franklin, J.F. 1988. Structural and functional diversity in temperate forests. In E.O. Wilson, editor. Biodiversity. Chapt. 18. Nat'l Acad. Press.

Franklin, J.F., K. Cromack, Jr., W. Denison, A. McKee, C. Maser, J. Sedell, F. Swanson, and G. Juday. 1981. Ecological characteristics of old-growth Douglas-fir forests. USDA Forest Service: Gen. Tech. Rep. PNW-118.

Franklin, J.F., H.H. Shugart and M.E. Harmon. 1987. Tree death as an ecological process. BioScience 37(8):550-556.

Franzreb, K.E. 1978. Tree species used by birds in logged and unlogged mixed-coniferous forests. Wilson Bull. 90(2):221-238.

Franzreb, K.E. and R.D. Ohmart. 1978. The effects of timber harvesting on breeding birds in a mixed-coniferous forest. Condor. 80:431-441.

Freeman, S. 1987 May 22. Acid rain trimming health of forests. The Springfield Union. 22 May 1987:17.

French, J. 1988. MDC-DFWELE Land Acquisition Program: MDC Watersheds. Commonwealth of Massachusetts. Unpublished MDC report.

Geldreich, E.E. 1972. Water-borne pathogens. In Mitchell (editor). Water pollution microbiology. Chapter 9. New York: John Wiley & Sons.

Geldreich, E.E. 1978. Bacterial populations and indicator concepts in feces, sewage, stormwater and solid wastes. In G. Berg, editor. Indicators of viruses in water and food. 51-97. Michigan: Ann Arbor Science Publ. Inc.

Gill, J.D., J.W. Thomas, W.M. Healy, J.C. Pack and H.R. Sanderson. 1975. Comparison of seven forest types for game in West Virginia. J. Wildlf. Manage. 39:762-768.

Gore, J.A. 1988. Habitat structure and the distribution of small mammals in a northern hardwood forest. In Szaro et al., editors. Management of Amphibians, Reptiles and Small Mammals in North America. 319-327. USDA Forest Service: Gen. Tech. Rep. RM-166.

Gore, J.A. 1986. Small mammals and habitat structure in an old-growth northern hardwoods forest. University of Massachusetts: PhD dissertation.

Gould, D.J. and M.R. Fletcher. 1978. Gull droppings and their effects on water quality. Wat. Res. 12:665-672.

Griffin, C.R. n.d. Red maple forested wetlands: review of major characteristics and values. University of Massachusetts: Unpub. report.

Hakason, L., Andersson, T, and A. Nilsson. 1990. New method of quantitatively describing drainage areas. Environ. Geol. Sci. 15(1):61-69.

Halls, L.K. and R. Alcaniz. 1968. Browse plants yield best in forest openings. J. Wildlf. Manage. 32:185-186.

Hansen, A.J., T.A. Spies, F.J. Swanson and J.L. Ohmann. 1991. Conserving biodiversity in managed forests: lessons from natural forests. BioScience. 41(6):382-392.

Harris, L. D. 1984. The Fragmented Forest. Chicago: Univ. of Chicago Press.

Hartley, B.A. 1975. Current management practices on the Baltimore municipal watersheds. USDA Forest Service: General Technical Report NE-13.

Hartman, E.M., P.E. Austin, and K.M. Keohane. 1992. Quabbin tributaries: water quality data report. Commonwealth of Massachusetts: DEP and MDC Pub. No. 17158-195-50.

Healy, W.M. 1989. Uneven-age silviculture and wildlife habitat. In J.C. Finley and M.C.

Brittingham, editors. Timber management and its effects on wildlife. Proc. 1989 Penn. State For. Res. Issues Conference. 225-237. Pennsylvania State University.

Healy, W.M., R.T. Brooks and R.M. DeGraaf. 1989. Cavity trees in sawtimber-size oak stands in central Massachusetts. North. J. Appl. For. 6(2):61-65.

Healy, W.M., R.T. Brooks and P.J. Lyons. 1987. Deer and forests on Boston's municipal watershed after 50 years as a wildlife sanctuary. In Proceedings: Deer, Forestry, and Agriculture - Interactions and Strategies for Management. June 15-17, 1987. Warren, PA. Allegheny Society of American Foresters.

Hemond, H.F. and K.N. Eshleman. 1984. Neutralization of acid deposition by nitrate retention at Bickford Watershed, Massachusetts. Water Resources Research. 20(11):1718-1724.

Hemond, H., K. Eshleman, K. O'Connor, B. Gordesky, and D. Chen. 1987. Surface hydrology and wetland roles in acid deposition on the Bickford Pond watershed. Commonwealth of Massachusetts: Dept. Env. Qual. Eng. Project 84-26 WPC.

Henry, J.D. and J.M.A. Swan. 1974. Reconstructing forest history from live and dead plant material - an approach to the study of forest succession in southwest New Hampshire. Ecol. 55:772-783.

Hewlett, J.D. 1978. Forest water quality: an experiment in harvesting and regenerating of Piedmont forest. Athens: University of Georgia.

Hewlett, J.D. and W.L. Nutter. 1970. The varying source area of streamflow from upland basins. In Proceedings of the Symposium on Interdisciplinary Aspects of Watershed Management. 65-83. Montana State University: American Society of Civil Engineers.

Hewlett, J.D. and W.L. Nutter. 1969. An outline of forest hydrology. Athens, GA: University of Georgia Press.

Hibbert, A.R. 1967. Forest treatment effects on waters yield. In W.E. Sopper and H.W. Lull, editors. International Symposium on Forest Hydrology. 527-543. Oxford: Pergamon Press.

Hill, E.P. 1982. In J.A. Chapman and G.A. Feldhammer, editors. Wild mammals of North America: biology, management and economics. Beaver:256-281. John Hopkins Univ. Press.

Hodkinson, I.D. 1975. Energy flow and organic matter decomposition in an abandoned beaver pond ecosystem. Oecologia 21:131-139.

Holmes, R.T. and S.K. Robinson. 1981. Tree species preferences of foraging insectivorous birds in a northern hardwoods forest. Oecologia 48:31-35.

Hornbeck, J.W., Adams, M.B., Corbett, E.S., Verry, E.S., and J.A. Lynch. 1993. Long-term impacts of forest treatments on water yield: a summary of northeastern USA. Journal of Hydrology. 150:323-344.

Hornbeck, J.W. and A. Federer. 1975. Effects of management practices on water quality and quantity: Hubbard Brook Experimental Forest, New Hampshire. USDA Forest Service: General Technical Report NE-13.

Hornbeck, J.W., C.W. Martin, and C.T. Smith. 1986. Protecting forest streams during whole-tree harvesting. Northern Journal of Applied Forestry 3(Sept): 97-100.

Hornbeck, J.W., R.S. Pierce, G.E. Likens, and C.W. Martin. 1975. Moderating the impact of contemporary forest cutting on hydrologic and nutrient cycles. In The Hydrological Characteristics of River Basins Symposium. 423-433. IAHS-AISH Publication No. 117.

Hunt, F.M. 1961. Forest resources on Metropolitan District Commission lands surrounding Quabbin Reservoir. Master's Thesis. University of Massachusetts, Amherst.

Hunt, F.M. 1991. Personal communication. Former MDC Chief Forester.

Hunt, F.M. and D.L. Mader. 1970. Low density management - a means to increase timber yields while using less soil moisture. University of Massachusetts: Mass. Agric. Exp. Station Bulletin No. 588 (November).

Hunter, M.L. 1990. Wildlife, forests and forestry: principles of managing forests for biological diversity. New Jersey: Prentice-Hall.

Hurst, G.A., D.C. Guynn and B.D. Leopold. 1979. Correlation of forest characteristics with white-tailed deer forage. Proc. Ann. Conf. S.E. Assoc. F & W Agencies. 33:48-55.

Hussong, D., J.M. Damare, R.J. Limpert, W.J.L. Sladenk, R.M. Weiner and R.R. Colwell. 1979. Microbial impact of Canada Geese (Branta canadensis) and Whistling Swans (Cygnus columbianus columbianus) on aquatic ecosystems. Appl. Envir. Microbiol. 37:14-20.

Irland, L.C. 1982. Wildlands and Woodlots: The Story of New England's Forests. Hanover, New Hampshire: University Press of New England.

Ives, R.L. 1942. The beaver-meadow complex. J. Geomorphol. 5:191-203.

James, F.C. and N.O. Wamer. 1982. Relationships between temperate forest bird communities and vegetation structure. Ecology 63:159-171.

Johnson, P.L. and W.T. Swank. 1973. Studies of cation budgets in the southern Appalachians on four experimental watersheds with contrasting vegetaion. Ecology 54(1):70-80.

Johnston, C.A. and R.J. Naiman. 1990. Browse selection by beaver: effects on riparian forest composition. Can. J. For. 20:1036-1043.

Johnston, W.S., G.K. Maclachlan and G.F. Hopkins. 1979. The possible involvement of seagulls (Larus sp.) in the transmission of salmonella in dairy cattle. Veterinary Record. 105:526-527

Jones, F., P. Smith and D.C. Watson. 1978. Pollution of a water supply catchment by breeding gulls and the potential environmental health implications. J. Inst. Wat. Eng. & Sci. 32:469-482.

Jones, W.R. 1951. The deer herd of Prescott Peninsula, Quabbin Reservation, and its ecology. University of Massachusetts: Master's thesis.

Kennelly, J.J. and P.J. Lyons. 1983. Evaluation of induced sterility for beaver management problems. Proc. Eastern Wildlife Damage Control Conference. 1:169-175.

Klein, R.M. and T.D. Perkins. 1988. Primary and secondary causes and consequences of contemporary forest decline. Botanical Review. 54(1): 1-43.

Knierim, P.G., K.L. Carvell and J.D. Gill. 1971. Browse in thinned oak and cove hardwood stands. J. Wildlf. Manage. 35:163-168.

Kochenderfer, J.N. and G.M. Aubertin. 1975. Effects of management practices on water quality and quantity: Fernow Experimental Forest, West Virginia. In Municipal Watershed Management Symposium Proceedings. 14-24. USDA Forest Service: General Technical Report NE-13.

Kochenderfer, J.N. and J.D. Helvey. 1974. Gravel greatly reduces soil losses from minimum-standard forest roads. USDA Forest Service: West Virginia.

Kochenderfer, J.N, J.D. Helvey, and G.W. Wendel. 1987. Sediment yield as a function of land use in central Appalachian forests. Knoxville, TN: Sixth Central Hardwood Forest Conference.

Krefting, L.W. and R.L. Phillips. 1970. Improving deer habitat in Upper Michigan by cutting mixed conifer swamps. J. For. 68(1):701-704.

Krug, E.C. and C.R. Frink. 1983. Acid rain on acid soil: a new perspective. Science 221: 520-525.

Kyker-Snowman, T. 1989a. 1989 Quabbin forest regeneration study. Commonwealth of Massachusetts: MDC Publication.

Kyker-Snowman, T. 1989b. Logging systems evaluation on the Wachusett Reservoir, November, 1989: summary of evaluation and analysis. Commonwealth of Massachusetts: MDC Publication.

Larson, F.R., P.F. Ffolliott, W.O. Rasmussen, and D.R. Carder. 1979. Estimating impacts of silvicultural management practices on forest ecosystems. In Best Management Practices for Agriculture and Silviculture: Proceedings of the 1978 Cornell Agricultural Waste Management Conference. Michigan: Ann Arbor Science Publishers Inc.

Layman, S.A. and R.H. Barrett. 1986. Developing and testing habitat capability models: pitfalls and recommendations. In J. Verner, M.L. Morrison and C.J. Ralph, editors.

Wildlife 2000: Modeling habitat relationships of terrestrial vertebrates. 87-91. University of Wisconsin Press.

Leahy, C.W. 1988 Eden's end; a case for ecological protection in Massachusetts. Mass. Audubon Society: presented at Wildlife Futures Conference.

Leak, W.B. 1973. Species and structure of a virgin northern hardwood stand in New Hampshire. USDA Forest Service: Research Note NE-181.

Leak, W.B. 1969. Stocking of northern hardwood regeneration based on exponential dropout rate. Forestry Chronicle 45(Oct): 344-347.

Leak, W.B. and J.H. Gottsacker. 1985. New approaches to uneven-age Management in New England. North. J. Appl. For. 2:28-31.

Leak, W.B. and W. Martin. 1975. Relationship of stand age to streamwater nitrate in New Hampshire. USDA Forest Service Research Note NE-21.

Lee, J.J. and D.E. Weber. 1982. Effects of sulfuric acid rain on major cation and sulfate concentrations of water percolating through two model hardwood forests. J. Environ. Qual. 11(1): 57-64.

Leland, D.E. and P.A. Berg. 1988. Assessing unfiltered water supplies. Jour. AWWA.

Lent, R. and D.R. Smith (editors). 1994. Harvard University: Abstracts of 4th Annual Harvard Forest Ecology Symposium.

Leonard, W.C., R.F. Yuretich and S.J. Pohanka. 1984. Hydrogeology and processes of acid neutralization in Cadwell Creek, Quabbin Reservation, Massachusetts. University of Massachusetts: Water Resources Research Center Publication No.148.

Li, R.M., K.G. Eggert, and D.B. Simons. 1979. Simulation of stormwater runoff and sediment yield for assessing the impact of silvicultural practices. In Best Management Practices for Agriculture and Silviculture: Proceedings of the 1978 Cornell Agricultural Waste Management Conference. Michigan: Ann Arbor Science Publishers Inc.

Likens, G.E. 1970. Effects of deforestation on water quality. In Proceedings of the Symposium on Interdisciplinary Aspects of Watershed Management. 133-140. Montana State University: American Society of Civil Engineers.

Litvaitis, J.A., J.A Sherburne and J.A. Bissonette. 1985. Influence of understory characteristics on snowshoe hare habitat use and density. J. Wildlf. Manage. 49:866-873.

Livingston, S.A., C.S. Todd, W.B. Krohn and R.B. Owen. 1990. Habitat model for nesting bald eagles in Maine. J. Wildl. Manage. 54(4)644-653.

Lull, H.W. and K.G. Reinhart. 1972. Forests and floods in the eastern United States. In A.R. Eschner and P.E. Black, editors. Readings in Forest Hydrology. New York: MSS Information Corp.

Lull, H.W. and K.G. Reinhart. 1967. Increasing water yield in the northeast by management of forested watersheds. USDA Forest Service: Research Paper NE-66.

Lynch, J.A., W.E. Sopper, E.S. Corbett, and D.W. Aurand. 1975. Effects of management practices on water quality and quantity: the Pennsylvania State Experimental Watersheds. In Municipal Watershed Management Symposium Proceedings. 32-46. USDA Forest Service: General Technical Report NE-13.

MacArthur, R.H. 1958. Population ecology of some warblers of northeastern coniferous forests. Ecology. 39:599-619.

MacArthur, R.H. and E.O. Wilson. 1967. The theory of island biogeography. New Jersey: Princeton Univ. Press.

Mader, D.L., W.P. MacConnell, and J.W. Bauder. 1972. The effect of riparian vegetation control and stand density reduction on soil moisture in the riparian zone. University of Massachusetts: Agric. Exp. Station Research Bulletin No. 597(Sept.).

Malben, G. and J.B. Foote. 1955. Beaver activity and water quality. J. Amer. Water Works Assoc. 47:503-507.

Manion, P.D. 1981. Tree Disease Concepts. New Jersey: Prentice-Hall Inc.

Mannan, R.W. and E.C. Meslow. 1984. Bird populations and vegetation characteristics in managed and old-growth forests in northwestern Oregon. J. Wildlf. Manage. 48:1219-1238.

Marchand, P.J. 1987. North woods: An inside look at the nature of forests in the Northeast. Boston: Appalachian Mountain Club.

Marcuzzi, G. 1986. Man-beaver relations. In G. Pilleri, editor. Investigations of beavers. Vol V: 15-72. Berne, Switzerland: Brain Anatomy Inst. .

Marks, P.L. and F.H. Bormann. 1972. Revegetation following forest cutting: mechanisms for return to steady-state nutrient cycling. Science 176: 914-915.

Martin, C.W. 1988. Soil disturbance by logging in New England - review and management recommendations. Northern Journal of Applied Forestry. 5(March):30-34.

Martin, C.W. 1979. Precipitation and streamwater chemistry in an undisturbed forested watershed in New Hampshire. Ecology 60(1): 36-42.

Martin, C.W., D.S. Noel, and L.A. Fedrer. 1984. Effects of forest clearcutting in New England on stream chemistry. Journal of Environmental Quality. 13: 204-210.

Martin, C.W. and R.S. Pierce. 1980. Clearcutting patterns affect nitrate and calcium in streams in New Hampshire. Journal of Forestry. May: 268-272.

Maser, C., S.P. Cline, K. Cromack Jr., J.M. Trappe and E. Hansen. 1988. What we know about large trees that fall to the forest floor. In: From the forest to the sea: a story of fallen trees. USDA Forest Service: Gen. Tech. Report PNW-GTR-229.

Maser, C. and J.M. Trappe. 1984. The seen and unseen world of the fallen tree. USDA Forest Service: Gen. Tech. Rep. PNW-164.

Massachusetts Audubon Society. 1989. Ecological Management Plan Draft: Wachusett Meadow Wildlife Sanctuary, Princeton, MA.

Mathisen, J.E. 1983. Integrating wildlife habitat objectives with silvicultural prescriptions. Paper presented at Silvicultural Guides Workshop, Grand Rapids, MI, February, 1983.

McAvoy, D.C. 1989. Episodic response of aluminum chemistry in an acid-sensitive Massachusetts catchment. Water Resources Res. 25:(2)233-240.

McDowell, D.M. and R.J. Naiman. 1986. Structure and functionof a benthic invertebrate stream community as influenced by beaver (*Castor canadensis).* Oecologia 68:481-489.

McMinn, J.W. 1991. Biological diversity research: an analysis. USDA Forest Service: Gen. Tech. Rep. SE-71.

Metzmaker, J.B. and A.E. Rosquist Jr. 1986. Watershed monitoring to assess the risk of a *Giardia lamblia* contamination of unfiltered municipal water supplies. Proc. Int. Symp. on water-related health issues. AWRA: 145-151.

Meyer, J.L. and G.E. Likens. 1979. Transport and transformation of phosphorus in a forest stream ecosystem. Ecology. 60(6): 1255-1269.

Miller, D.R., M.J. Focazio, and M.A. Dickenson. 1986. A user's guide to a model for estimating the hydrological effects of land use change (BROOK). University of Massachusetts and University of Connecticut: cooperative Extension.

Monaghan, P., C.B. Shedden, K. Ensor, C.R. Fricker and R.W.A. Girdwood. 1985. Salmonella carriage by herring gulls in the Clyde area of Scotland in relation to their feeding ecology. J. Appl. Ecol. 22:669-680.

Monzingo, D.L., Jr. and C.P. Hibler. 1987. Prevalence of *Giardia* sp. in a beaver colony and the resulting environmental contamination. J. Wildlf. Dis. 23(4):576-585.

Moran, R. and J.R. Terry. 1987. Initial response of deer populations to experimental forest cuttings in Michigan. Mich. Dept. Nat. Res.: Wildlf. Div. Rep. No. 3010.

More, M.E. and J.W. Soper. 1990. GEIR Forestland Management Practices. Massachusetts Department of Environmental Management: EOEA File Number 6307.

Morse, D.H. 1976. Variables affecting the density and territory size of breeding spruce-woods warblers. Ecology. 57:290-301.

Mrazik, B.R., and D.L. Mader, and W.P. MacConnell. 1980. Integrated watershed management: an alternative for the northeast. University of Massachusetts: Mass. Agr. Exp. Station Research Publication 664.

Murdoch, P.S. and J.L. Stoddard. 1992. The role of nitrate in the acidification of streams in the Catskill Mountains of New York. Water Resources Res. 28(10): 2707-2720.

Myers, R.L. and P.A. Peroni. 1983. Approaches to determining aboriginal fire use and its impact on vegetation. Bulletin of the Ecological Society of America. 64:217-218.

Nadelhoffer, K.J., J.D. Aber and J.M. Melillo. 1984. Seasonal patterns of ammonium and nitrate uptake in nine temperate forest ecosystems. Plant and Soil. 80: 321-335.

Naiman, R.J. and J.M. Melillo. 1984. Nitrogen budget of a subarctic stream altered by beaver (*Castor canadensis*). Oecologia. 62:150-155.

Naiman, R.J., C.A. Johnston and J.C. Kelly. 1988. Alteration of North American streams by beaver. BioScience 38(11):753-762.

Naiman, R.J., J.M. Melillo and J.E. Hobbie. 1986. Ecosystem alteration of boreal forest streams by beaver (*Castor canadensis*). Ecology 67(5):1254-1269.

Neff, D.J. 1957. Ecological effects of beaver habitat abandonment in the Colorado Rockies. J.Wildlf. Manage. 21(1):80-84.

Nichols, G.E. 1913. The vegetation of Connecticut. Torreya 13(9):199-215.

Norvell, W.A. and C.R. Frink. 1975. Estimation of potential nutrient enrichment of Lake Wononscopomuc by wild geese. New Haven Conn. Agric. Exp. Station. Unpubl. manuscript

Noss, R.F. 1991. Sustainability and wilderness. Cons. Biol. 5(1):120-122.

Noss, R.F. 1987. From plant communities to landscapes in conservation inventories: a look at the Nature Conservancy (USA). Biol. Conserv. 41:11-37.

Nyberg, J.B., A.S. Harestad and F.L. Bunnell. 1987. "Old-growth" by design: managing young forests for old-growth wildlife. Trans. N.Amer. Wildlf. & Nat. Res. Conf. 52:70-81.

O'Connor, R.W. 1982a. Recreational use of drinking water reservoir watersheds. S.U.N.Y. Syracuse: Unpub. report.

O'Connor, R.W. 1982b. Comparison of streamflow simulations for three New England streams using "Brook 6" computer model. S.U.N.Y. Syracuse: Unpub. report.

O'Connor, R.W. and J. Zilligen. 1996. Wachusett watershed: MDC public access plan. Commonwealth of Massachusetts: MDC Report.

O'Gara, R. 1989a. Malden Brook Survey, 1/17/89-3/9/89. Commonwealth of Massachusetts: MDC Report.

O'Gara, R. 1989b. Malagasco Brook survey, November, 1989. Commonwealth of Massachusetts: MDC Report.

Odum, E. P. 1969. The strategy of ecosystem development. Science 164: 262-270.

Office Technol. Assess. 1987. Technologies to maintain biological diversity. Washington, D.C.: Off. Tech. Assess.

Oliver, C.D. and E.P. Stephens. 1977. Reconstruction of a mixed-species forest in central New England. Ecol. 58;562-572.

Ollinger, S., J. Aber and C. Federer. 1994. A GIS modeling approach to estimating regional carbon and water balances for the northeastern U.S. Harvard University: Abstracts from the 5th Annual Harvard Forest Ecology Symposium.

Ottenheimer, D.G. 1992. Hurricane susceptibility and water quality at Quabbin forest, Massachusetts. SUNY: Master's thesis.

Parker, D. 1988 June 16. Forest endangered: acid rain, ozone damage worsening. Springfield Union. 16 June 1988.

Parsons, W.F.J., D.H. Knight and S.L. Miller. 1994. Root gap dynamics in lodgepole pine forest: nitrogen transformations in gaps of different size. Ecol. Apps. 4(2):354-362.

Patric, J.H. 1978. Harvesting effects on soil and water in eastern hardwoods forests.

Southern Journal of Applied Forestry. 2(3): 66-73.

Patric, J.H. 1977. Soil erosion and its control in eastern woodlands. Northern Logger and Timber Processor. 25(11): 4-6.

Patric, J.H. 1976. Soil erosion in the eastern forest. J. Forestry, Oct: 671-677.

Patric, J.H. 1974. River flow increases in central New England after the hurricane of 1938. J. Forestry Vol 72(1), January.

Patric, J.H. and E.M. Gould. 1976. Shifting land use and the effects on river flow in Massachusetts. J of AWWA (Jan): 41-45.

Patric, J.H, J.O. Evans, and J.D. Helvey. 1984. Summary of sediment yield data from forested land in the United States. J. For. 82(2): 101-104.

Patterson, W.A. III and K.E. Sassaman. 1988. Indian fires in the prehistory of New England. In G. P. Nicholas (editor). Holocene Human Ecology in Northeastern North America. 107-131. New York: Plenum Press.

Perkey, A.W., B.L. Wilkins and H.C. Smith. 1993. Crop tree management in eastern hardwoods. USDA Forest Service: NA-TP-19-93.

Peters, N.E. and P.S. Murdoch. 1985. Hydrogeologic comparison of an acidic-lake basin with a neutral-lake basin in the west-central Adirondack Mountains, New York. Water, Air, and Soil Pollution. 26:387-402.

Petersen, C.M. nd. Forest resources of Massachusetts. University of Massachusetts: Coop. Ext. Serv. Publ. No. C198.

Petersen, C. and G.C. Smith. 1989. Are the forests of Massachusetts in decline? In Current Issues in Forestry. University of Massachusetts: Cooperative Extension. I(2).

Pickett, S.T.A. and P.S. White. 1985. The ecology of natural disturbance and patch dynamics. New York: Academic Press Inc.

Pierce, R.S. 1965. Evidence of overland flow on forest watersheds. In W.E. Sopper and

H.W. Lull, editors. Forest Hydrology: Proceedings of a National Science Foundation Advanced Science Seminar at Pennsylvania State University. 247-253. London: Pergamon Press.

Portnoy, J.W. 1974. Some ecological and behavioral aspects of a nesting population of red-shouldered hawks (*Buteo lineatus lineatus*). Univ. Massachusetts: Master's thesis.

Portnoy, J.W. 1990. Gull contributions of phosphorous and nitrogen to a Cape Cod kettle pond. Hydrobiologia 202:61-69.

Pough, F.H., E.M. Smith, D.H. Rhodes and A. Collazo. 1987. The abundance of salamanders in forest stands with different histories of disturbance. For. Ecol. Manage. 20:1-9.

Probst, J.R. 1979. Oak forest bird communities. In R.M. DeGraaf and K.E. Evans, editors. Management of NorthCentral and Northeastern forests for nongame birds. 80-88. USDA Forest Service: Gen. Tech. Rep. NC-51.

Ranney, J.W., M.C. Bruner and J.B. Levenson. 1981. The importance of edge in the structure and dynamics of forest islands. In R.L. Burgess and S.M. Sharpe, editors. Forest Island Dynamics in Man-dominated Landscapes. 67-96. New York: Springer-Verlag.

Raup, H.M. 1957. Vegetational adjustment to the instability of site. In Proc. 6th Tech. Meet. 1956 Int. Un. Conserv. Nature Nat. Resources. 36-48. Edinburgh.

Reese, K.P. and J.D. Hair. 1976. Avian species diversity in relation to beaver pond habitats in the Piedmont region of South Carolina. Proc. Southeast Assoc. F & W Agencies Conf. 30:437-447.

Reich, P.B. and R.G. Amundson. 1985. Ambient levels of ozone reduce net photosynthesis in tree and crop species. Science. 230:566-570.

Reid, D.G., S.M. Herrero and T.E. Code. 1988. River otters as agents of water loss from beaver ponds. J. Mammal. 69(1):100-107.

Remillard, M.M., G.K. Gruendling and D.J. Bogucki. 1987. Disturbance by beaver (*Castor canadensis*) and increased landscape heterogeneity. In M.G.Turner, editor. Landscape heterogeneity and disturbance: Chapt. 6. Ecological Studies 64. New York: Springer-Verlag.

Reinhert, R.H. and J.A. Hroncich. 1990. Source water quality management. In F.W. Pontius, editor. Water quality and treatment: a handbook of community water supplies. 189-228. AWWA: McGraw-Hill.

Renken, R.B. and E.P. Wiggers. 1989. Forest characteristics related to pileated woodpecker territory size in Missouri. The Condor 91:642-652.

Reuss, J.O. and D.W. Johnson. 1986. Acid Deposition and the Acidification of Soils and Waters. Ecological Studies. New York: Springer-Verlag.

Rice, E.L. and S.K. Pancholy. 1974. Inhibition of nitrification by climax ecosystems III. Amer. J. Bot. 161(10): 1095-1103.

Rice, E.L. and S.K. Pancholy. 1973. Inhibition of nitrification by climax ecosystems II. Amer. J. Bot. 60(7): 691-702.

Rice, E.L. and S.K. Pancholy. 1972. Inhibition of nitrification by climax ecosystems. Amer. J. Bot. 59(10): 1033-1040.

Rice, R.M., J.S. Rothacher, and W.F. Megahan. 1972. Erosional consequences of timber harvesting: an appraisal. In National Symposium on Watersheds in Transition. American Water Resources Association No. 14.

Rittmaster, R.L. and J.B. Shanley. 1990. Effects of atmospheric wet deposition on the water quality of two streams in the Quabbin Reservoir Watershed, Central Massachusetts, 1983-85. U.S. Geological Survey: Water-Resources Investigations Report 90.

Rivers, W.H. 1981. Draft environmental impact report for forestry activities on Department of Environmental Management lands. Commonwealth of Massachusetts: DEM.

Roach, B.A. 1974. Scheduling timber cutting for sustained yield of wood products and wildlife. USDA Forest Service: Gen. Tech. Rep. NE-14.

Robinson, J. B., H. R. Whiteley, W. Stammers, N. K. Kaushik, and P. Sain. 1979. The fate of nitrate in small streams and its management implications. In Best Management Practices for Agriculture and Silviculture: Proceedings of the 1978 Cornell Agricultural Waste Management Conference. 247-259. Ann Arbor Science Publishers.

Rondeau, R. 1989. French Brook Survey, November, 1989. Commonwealth of Massachusetts: MDC Report.

Rondeau, R. and R. O'Gara. 1990. Muddy Brook Survey, November, 1989. Commonwealth of Massachusetts: MDC Report.

Rondeau, R. and R. O'Gara. 1989. Gates Brook Field Work, October - December, 1988; Scarletts Brook Field Work, February - March, 1989. Commonwealth of Massachusetts: MDC Report.

Rose, J.B. 1988. Occurrence and significance of *Cryptosporidium* in water. J. Amer. Wat. Works Assoc. 53-58.

Roth, C.E. 1989. The water keepers. Mass. Audubon Soc. Sanctuary:Nov.

Rothacher, J. 1970. Managing forest land for water quality. Proceedings of the Joint FAO/U.S.S.R. International Symposium on Forest Influences and Watershed Management, Moscow, U.S.S.R. U.S.D.A. Forest Service.

Rudemann, R. and W.J. Schoonmaker. 1938. Beaver dams as geologic agents. Science. 88:523-525.

Russell, E.W.B. 1983. Indian-set fires in the forests of the Northeastern United States. Ecology. 64:78-88.

Russell, H.S. 1976. A Long, Deep Furrow: Three Centuries of Farming in New England. Hanover, NH: University Press of New England.

Rutherford, W.H. 1950. Wildlife and environmental relationships of beaver in Colorado forests. J. For. 53(11):803-806.

S.U.N.Y. 1981. New York river basins special studies: a proposed plan of forest land watershed management for the Schoharie Watershed. S.U.N.Y. Syracuse: unpublished.

Saaty, T. 1990. Decision making for leaders: the Analytic Hierarchy Process for decisions in a complex world. Pittsburgh, PA: University of Pittsburgh Press.

Salwasser, H. 1990. Conserving biological diversity: a perspective on scope and approaches. For. Ecol. Manage. 35:79-90.

Scanlon, J.J. 1992. Managing forests to enhance wildlife diversity in Massachusetts. Northeast Wildlife 49:1-9.

Schindler, D.W. 1988. Effects of acid rain on freshewater ecosystems. Scence. 239:149-157.

Schindler, D.W., R.W. Newbury, K.G. Beaty, J. Prokopowich, T. Ruszczynski, and J.A. Dalton. 1980. Effects of a windstorm and forest fire on chemical losses from forested watersheds and on the quality of receiving streams. Can. J. Aquat. Sci. 37:328-334.

Schoen, J.W., O.C. Wallmo and M.D. Kirchhoff. 1981. Wildlife-forest relationships: is a re-evaluation of old growth necessary? N.Amer. Wildl. Nat. Res. Conf. 46:531-544.

Schofield, C.L., J.N.Galloway and G.R. Hendry. 1985. Surface water chemistry in the Ilwas Basins. Water, Air, and Soil Pollution. 26:403-423.

Schueler, T. 1987. Controlling urban runoff: a practical manual for planning and designing urban BMP's. Prepared for the Washington Metropolitan Water Resources Planning Board.

Seton, J.R. 1929. Lives of game animals. Vol 4, Part 2. New York:Doubleday/ Doran.

Shaw, S.P. 1948. The beaver in Massachusetts: a research and management study. Mass. Dept. Cons., Res. Bull. #11.

Skeffington, R.A. and E.J. Wilson. 1988. Excess nitrogen deposition: issues for consideration. Environmental Pollution. 54:159-184.

Smith, M.E., C.T. Driscoll, B.J. Wyskowski, C.M. Brooks and C.C. Cosentini. 1991.

Modification of stream ecosystem structure and function by beaver (*Castor canadensis*) in the Adirondack Mountains, New York. Can. J. Zool. 69:55-61.

Smith, D.M. 1962. The practice of silviculture. 7th edition. New York: John Wiley and Sons.

Smith, D.M. 1986. The practice of silviculture. 8th edition. New York: John Wiley and Sons.

Smith, W.H. 1981. Air pollution-effects on the structure and function of the temperate forest ecosystem. In Air Pollution and Forests. New York: Springer-Verlag.

Soule, M., editor. 1987. Viable Populations for Conservation. Cambridge Univ. Press.

Speight, M.R. and D. Wainhouse. 1989. Ecology and Management of Forest Insects. Oxford:Clarendon Press.

Spencer, B.A. and P.J. Lyons. 1986. A ten-year forest and wildlife management plan for the Quabbin watershed. Commonwealth of Massachusetts: Unpublished MDC document.

Spencer, B.A. and C.T. Walker. 1972. Watershed Management Plan for Metropolitan District Commission lands surrounding Quabbin Reservoir. Commonwealth of Massachusetts: Unpublished MDC document.

Speranza, D.E. 1988. An investigation of *Giardia lamblia* in the Quabbin and Wachusett reservoirs. Univ. Massachusetts: Master's thesis.

Spurr, S.H. and B.V. Barnes. 1980. Forest ecology (third edition). New York: John Wiley and Sons, Inc.

Standridge, J.H., J.J. Delfino, L.B. Kleppe and R. Butler. 1979. Effect of waterfowl (Anas platyrhynchos) on indicator bacteria populations in a recreational lake in Madison, Wisconsin. Appl. Envir. Microbiol. 38:547-550.

State of Connecticut, South Central Connecticut Regional Water Authority. 1983. Forest management plan for south central Connecticut (draft).

State of Connecticut, South Central Connecticut Regional Water Authority. 1989. Forest management plan for south central Connecticut. Unpubl. doc.

State of New Hampshire, Department of Resources and Economic Development. 1994. Nash Stream Forest Management Plan (draft).

State of New Jersey, Department of Environmental Protection, Division of Parks and Forestry, Bureau of Forest Management. 1984. Forest resource plan for High Point State Park.

State of Vermont. n.d. Roxbury State Forest Plan.

Stekl, P.J. 1985. A hydrological investigation of two small watersheds of the eastern Quabbin basin. Univ. of Massachusetts, Amherst. Master's thesis.

Stephens, E.P. 1956. The uprooting of trees: a forest process. Soil Sci. Soc. Proc. 113-116.

Stevens, W.K. 1990 July 31. New eye on nature: the real constant is eternal turmoil - the "balance" theory may be more poetry than science. New York Times. 31 July 1988: C1, C2.

Stoddard, J.L. 1991. Trends in Catskill stream water quality: evidence from historical data. Water Resources Res. 27(11):2855-2864.

Stone, E.L. 1973. The impact of timber harvest on soils and water. In: Report of the President's Advisory Panel on Timber and the Environment, April 1973. 427-467.

Stone, E.L., W.T. Swank, and J.W. Hornbeck. 1979. Clearcutting versus alternative timber harvest and regeneration systems: impacts on soils and streamflow in the eastern deciduous region. USDA Forest Service.

Storey, H.C. and I.C. Reigner. 1970. Vegetation management to increase water yields. In Proceedings of the Symposium on Interdisciplinary Aspects of Watershed Management. 271-293. New York: American Society of Civil Engineers.

Suurballe, N.C. 1992. Effects of a wetland on quality of Natty Pond Brook, Massachusetts, 1985-86. USGS: Water-Resources Investigations Report 91-4144.

Swank, W.T. 1972. Water balance, interception, and transpiration studies on a watershed in the Pudget Lowland region of western Washington. U.Washinton: PhD Dissertation.

Sweeney, B.W. 1993. Effects of streamside vegetation on macroinvertebrate communities of White Clay Creek in eastern North America. Pro. Acad. Nat. Sci. of Philadelphia (144)-291-340.

Tamm, C.O. 1991. Nitrogen in terrestrial ecosystems: questions of productivity, vegetational changes, and ecosystem stability. Berlin: Springer-Verlag.

Tate, C.M. and J.L. Meyer. 1983. The influence of hydrologic conditions and successional state on dissolved organic carbon export from forested watersheds. Ecology 64(1):25-32.

Temple, S.A., M.J. Mossman and R.W. Titterington. 1979. The ecology and management of avian communities in mixed hardwood-coniferous forests. In R.M. DeGraaf and K.E. Evans, editors. Management of North Central and Northeastern forests for nongame birds. 132-153. USDA Forest Service: Gen. Tech. Rep. NC-51.

The Wildlife Society. 1990. Conservation policies of The Wildlife Society: A stand on issues important to wildlife conservation. Bethesda, Md.

Thomas, J.W. 1991. Research on wildlife in old-growth forests: an attempt at perspective. In Ruggiero et al., editors. Wildlife and vegetation of unmanaged Douglas-fir forests. USDA Forest Service: Gen. Tech. Rep. PNW-GTR-285.

Thomas, J.W., tech. editor. 1979. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. USDA Forest Service: Agric. Handbook. No. 553.

Thomas, J.W. and H. Salwasser. 1989. Bringing conservation biology into a position of influence in natural resource management. Conserv. Biol. 3(2):123-127.

Thompson, D.Q. and R.H. Smith. The forest primeval in the Northeast - a great myth? Publication information unknown; 10-page text on file at Natural Resources Office, Quabbin.

Thompson, C.H. and T.D. Kyker-Snowman. 1989. Evaluation of non-point source pollution problems from crossing streams with logging equipment and off-road vehicles in Massachusetts: 1987-88. Part I: timber harvesting operations. Commonwealth of Massachusetts: Department of Environmental Protection, Division of Water Pollution

Control Research and Demonstration Project 88-03 and Department of Environmental Management, Division of Forest and Parks.

Timmons, D.R., E.S. Verry, R.E. Burwell, and R.F. Holt. 1977. Nutrient transport in surface runoff and interflow from an aspen-birch forest. J. Environ. Qual. 6(2): 188-192.

Trimble, G.R. Jr., J.H. Patric, J.D. Gill, G.H. Moelleer, and J.N. Kochenderfer. 1974. Some options for managing forest land in the central Appalachians. USDA Forest Service: General Technical Report NE-12.

Tubbs, C.H., R.M. DeGraaf, M. Yamasaki and W.M. Healy. 1987. Guide to wildlife tree management in New England northern hardwoods. USDA Forest Service: Gen. Tech. Rep. NE-118.

Tzipori, S. 1983. Cryptosporidiosis in animals and humans. Microbiol. Rev. 47:84.

U.S.D.A. Forest Service. 1986. Land and Resource Management Plan: White Mountain National Forest.

U.S.D.A. Forest Service. n.d. Proposed Land and Resource Management Plan: Green Mountain National Forest.

U.S. Environmental Protection Agency. 1993. Handbook: urban runoff pollution prevention and control planning. U.S. Publication No. EPA/625/R-93/004.

Van Miegroet, H. and D.W. Johnson. 1993. Nitrate Dynamics in Forest Soils. In T.P. Burt et al., editors. Nitrate: Processes, Patterns and Management. 75-97. New York: Wiley & Sons.

Vellidis, G. 1994. Restoration of riparian wetlands: a case study. In Proceedings: Riparian Buffer Zones Conference. Society of Soil Scientists of Southern New England.

Veneman, P.L.M. 1984. Evaluation of the buffering capacity of Massachusetts soils to negotiate the impact of acid deposition on water quality. Completion Report to the Massachusetts Dept. of Environmental Quality Engineering Division of Air Quality Control. University of Massachusetts.

Verry, E.S. 1986. Forest harvesting and water: the Lake States experience. AWRA Bull. 22(6): 1039-1047.

Verner, J. 1984. The guild concept applied to management of bird populations. Envir. Manage. 8:1-14.

Vignaly, V.P., S.A. Campbell, and D.H. Small. 1994. Erosion and Sediment Control Manual. Commonwealth of Massachusetts: DWM EQ Section.

Vitousek, P.M. 1985. Community turnover and ecosystem nutrient dynamics. In Pickett, S.T.A. and P.S. White, editors. The Ecology of Natural Disturbance and Patch Dynamics. 325-333. New York: Academic Press Inc.

Vitousek, P.M. 1977. The regulation of element concentrations in mountain streams in the northeastern United States. Ecological Monographs 47: 65-87.

Vitousek, P.M., J.R. Gosz, C.C. Grier, J.M. Melillo, and W.A. Reiners. 1982. A comparative analysis of potential nitrification and nitrate mobility in forest ecosystems. Ecological Monographs 52(2): 155-177.

Vitousek, P.M., J.R. Gosz, C.C. Grier, J.M. Melillo, W.A. Reiners and R.L. Todd. 1979. Nitrate losses from disturbed ecosystems. Science 204:469-474.

Vitousek, P.M. and J.M. Melillo. 1979. Nitrate losses from disturbed forests: patterns and mechanisms. Forest Science 25(4): 605-619.

Vitousek, P.M. and W.A. Reiners. 1975. Ecosystem succession and nutrient retention: a hypothesis. Bioscience 25:376-381.

von Oettingen, S.L. 1982. A survey of beaver in central Massachusetts for *Giardia lamblia*. M.S. Thesis. Univ. Massachusetts, Amherst.

Walker, W.W., Jr. 1983. Significance of eutrophication in water supply reservoirs. J. Amer. Water Works Assoc. 75(1):38-42.

Webb, W.L., D.F. Behrend and B. Saisorn. 1977. Effect of logging on songbird populations in a northern hardwood forest. Wildlf. Monograph. 55.

Webster, B. 1983 January 11. The shy beaver: powerful effects on ecology seen in new research. New York Times. 11 January 1983.

Welsh, C.J. 1992. Bird species diversity and composition in managed and unmanaged tracts of northern hardwoods in New Hampshire. University of Massachusetts: PhD dissertation.

Welsh, H.H. Jr. and A.J. Lind. 1988. Old growth forests and the distribution of terrestrial herpetofauna. In Szaro et al., editors. Management of Amphibians, Reptiles and Small Mammals in North America. 439-455. USDA Forest Service: Gen.Tech. Rep. RM-166.

Western, D. 1991. Biology and conservation: making the relevant connection. Cons. Biol. 5(4):431-433.

Whipkey, R.Z. 1970. Theory and mechanics of subsurface stormflow. In Proceedings of the Symposium on Interdisciplinary Aspects of Watershed Management. 255-257. Montana State University: American Society of Civil Engineers.

Whitcomb, R.F., C.S. Robbins, J.F. Lynch, B.L. Whitcomb, M.K. Klimkiewicz and D. Bystrak. 1981. Effects of forest fragmentation on avifauna of the eastern deciduous forest. In R.L. Burgess and D.M. Sharpe, editors. Forest Island Dynamics in Man-dominated Landscapes. Chapt. 8. New York: Springer-Verlag.

Whitcomb, B.L., R.F. Whitcomb and D. Bystrak. 1977. Long-term turnover and effects of selective logging on the avifauna of forest fragments. Amer. Birds. 31(1):17-23.

White, P.S. 1979. Pattern, process, and natural disturbance in vegetation. Botanical Review. 45(Sept.):229-299.

Whitney, G.G. 1991. Relation of plant species to substrate, landscape position, and aspect in north central Massachusetts. Canadian Journal of Forestry Research. 21:1245-1252.

Wilcove, D.S. 1989. Forest fragmentation as a wildlife management issue in the Eastern U.S. In R.M. DeGraaf and W.M. Healy, editors. Is Forest Fragmentation a management issue in the northeast? 1-5. USDA Forest Service: Gen. Tech. Rep. NE-140.

Wilcove, D.S. 1985. Nest predation in forest tracts and the decline of migratory songbirds. Ecology. 66:1211-1214.

Wilcove, D.S., C.H. McClellan and A.P. Dobson. 1986. Habitat fragmentation in the temperate zone. In M.E. Soule, editor. Conservation Biology. 237-256. Sunderland, MA: Sinauer Assoc.

Wilde, S.A., C.T. Youngberg and J.H. Hovind. 1950. Changes in composition of ground water, soil fertility and forest growth produced by the construction and removal of beaver dams. J. Wildl. Manage. 14(2):123-128.

Wilen, B.O., W.P. McConnell and D.L. Mader. nd. The effects of beaver activity on water quantity and quality. Univ. of Mass., Amherst. Unpublished manuscript.

Williams, T.M. and A.C. Mace Jr. 1974. Effects of alternative harvesting systems on cycling of major nutrients in a forest soil. In Proceedings of the Society of American Foresters.

Wischmeier, W.H. and D.D. Smith. 1960. A universal soil-loss equation to guide conservation farm planning. Seventh International Congress Soil Science Trans. 1: 418-25.

Woo, M-K., and J.M. Waddington. 1990. Effects of beaver dams on subarctic wetland hydrology. Arctic. 43(3):223-230.

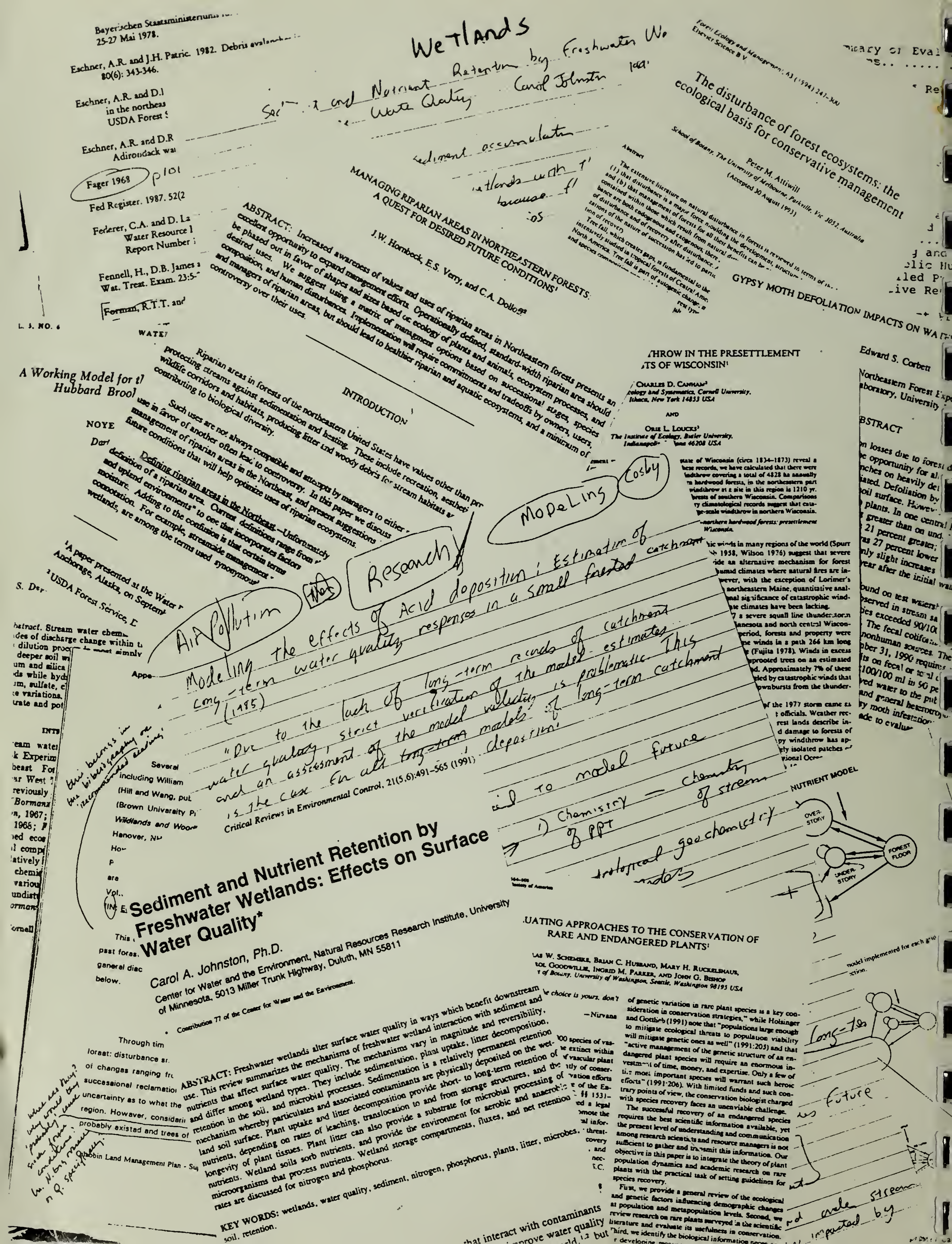
Wrath, L.C. 1970. The Voyages of Giovanni da Verrazzano, 1524-1528. New Haven: Yale University Press.

Yoshida, S. and M. Ichikuni. 1989. Role of forest canopies in the collection and neutralization of airborne acid substances. The Science of the Total Environment. 84:35-43.

Yuretich, R. (editor). 1992. Impacts of acid deposition on watersheds of the Quabbin reservoir. University of Massachusetts: Water Resources Research Center Publication No.166.

Yuretich, R.F., P.J. Stekl and S.J. Pohanka. 1986. Hydrogeology and mineral weathering reactions in watersheds of central Massachusetts. University of Massachusetts: Water Resources Research Center Pub. No. 152.

Zeedyk, W.D. and K.E. Evans. 1975. Silvicultural options and habitat values in deciduous forests. In D.R. Smith, editor. Proc. Symp. on management of forest and range habitats for nongame birds. 115-127. USDA Forest Service: Gen. Tech. Rep. WO-1.



Bayerischen Staatsministeriums ...
25-27 Mai 1978.

Eschner, A.R. and J.H. Patric. 1982. Debris avalanche...
80(6): 343-346.

Eschner, A.R. and D.
in the northeas
USDA Forest

Eschner, A.R. and D.R
Adirondack wa

Fager 1968 p101

Fed Register. 1987. 52(2

Federer, C.A. and D. La
Water Resource
Report Number

Fennell, H., D.B. James
Wat. Treat. Exam. 23:5-

~~Forman, R.T.T. and~~

WETLANDS

Sed... and Nutrient Retention by Freshwater W... 1991
... Water Quality Carol Johnston

sediment accumulation

wetlands with ...
because ...

Forest Ecology and Management, 63 (1994) 247-300
Elsevier Science B.V.

The disturbance of forest ecosystems: the ecological basis for conservative management

Peter M. Attiwill

School of Botany, The University of Melbourne, Parkville, Vic 3052, Australia

(Accepted 30 August 1993)

Abstract

The extensive literature on natural disturbance in forests is reviewed in terms of ... (1) that disturbance is a major force shaping the development, structure ... and (b) that management of forests for all their benefits can be ... contained within those which result from natural ... bance are both endogenous and exogenous; there ... of disturbance and of recovery after disturbance ... of the nature of succession has led to ... tion of recovery. Tree fall, which creates gaps, is fundamental to the ... intensively studied in tropical forests of Central Ame... North America. Tree fall is part of autogenic change ... and species composition ...

MANAGING RIPARIAN AREAS IN NORTHEASTERN FORESTS: A QUEST FOR DESIRED FUTURE CONDITIONS[1]

J.W. Hornbeck, E.S. Verry, and C.A. Dolloff

ABSTRACT: Increased awareness of values and uses of riparian areas in Northeastern forests presents an excellent opportunity to expand management efforts. Operationally defined, standard-width riparian areas should be phased out in favor of shapes and sizes based on ecology of plants and animals, ecosystem processes, and desired uses. We suggest using a matrix of management options based on successional stages, species composition, and human disturbances. Implementation will require commitments and tradeoffs by owners, users, and managers of riparian areas, but should lead to healthier riparian and aquatic ecosystems, and a minimum of controversy over their uses.

INTRODUCTION

Riparian areas in forests of the northeastern United States have values other than pr... protecting streams against sedimentation and heating. These include recreation, aesthet... wildlife corridors and habitats, producing litter and woody debris for stream habitats ar... contributing to biological diversity.

Such uses are not always compatible and attempts by managers to either ... use in favor of another often lead to controversy. In this paper we discuss ... management of riparian areas in the Northeast, and present suggestions ... future conditions that will help optimize uses of riparian ecosystems.

Defining riparian areas in the Northeast.—Unfortunately definition of a riparian area. Current definitions range from ... and upland environments" to one that incorporates factors ... moisture. Adding to the confusion is that certain terms ... connotation. For example, streamside management ... wetlands, are among the terms used synonymous...

[1]A paper presented at the Water ... Anchorage, Alaska, on Septem...

[2]USDA Forest Service, ...

GYPSY MOTH DEFOLIATION IMPACTS ON WA...

Edward S. Corbett

Northeastern Forest Exp... Laboratory, University ...

ABSTRACT

...n losses due to forest d... the opportunity for al... inches on heavily de... ated. Defoliation by ... soil surface. Howev... plants. In one central ... greater than on und... 21 percent greater; ... 27 percent lower ... only slight increases ... year after the initial wa...

...ound on test waters ... observed in stream sa... ...ies exceeded 90/100 ... The fecal colifo... nonhuman sources. The ... ber 31, 1990 requires ... its on fecal or total c... 100/100 ml in 90 pe... ved water to the pu... and general heterotro... ...y moth infestation ... ade to evalua...

...THROW IN THE PRESETTLEMENT ...TS OF WISCONSIN[1]

CHARLES D. CANHAM[2]
...cology and Systematics, Cornell University, Ithaca, New York 14853 USA

AND

ORIE L. LOUCKS[3]
The Institute of Ecology, Butler University, Indianapolis, ... 46208 USA

...state of Wisconsin (circa 1834–1873) reveal a ... these records, we have calculated that there were ... windthrow covering a total of 4828 ha annually ... hardwood forests, in the northeastern part ... windthrow at a site in this region is 1210 yr. ... forests of southern Wisconsin. Comparisons ... climatological records suggest that cata... ...ge-scale windthrow in northern Wisconsin.

...northern hardwood forests; presettlement Wisconsin.

...ic winds in many regions of the world (Spurr ... 1958, Wilson 1976) suggest that severe ... ride an alternative mechanism for forest ... humid climates where natural fires are in... ...wever, with the exception of Lorimer's ... northeastern Maine, quantitative anal... ...nal significance of catastrophic wind... ...te climates have been lacking. ...7 a severe squall line thunderstorm ... ...nesota and north central Wiscon... period, forests and property were ... winds in a path 266 km long ... (Fujita 1978). Winds in excess ... uprooted trees on an estimated ... Approximately 7% of these ... led by catastrophic winds that ... ownbursts from the thunder...

...f the 1977 storm came as ... officials. Weather rec... ...rest lands describe in... ...d damage to forests of ... windthrow has ap... ...ly isolated patches of ... ...ional Oce...

L. 5, NO. 6 WATE...

A Working Model for t... Hubbard Brool...

NOYE...

Dari...

S. Der...

...bstract. Stream water chem... ...ides of discharge change within t... dilution proc... deeper soil w... ...um and silica ... ...ds while hyd... ...m, sulfate, c... ...e variations, ...trate and pot...

INTR...

...eam water ...k Experim... ...beast. Fo... ...ar West ... ...reviously ... Borman... ...n, 1967; ... 1968; ... ...ed eco... ...l comp... ...atively ... chemi... variou... undist... orman...

...ornell

Air Pollution that Research Modeling Cosby

Modeling the effects of Acid deposition: Estimation of long-term water quality responses in a small ~~forested~~ catchment (1985)

"Due to the lack of long-term records of catchment water quality, strict verification of the model estimates and an assessment of the model validity is problematic. This is the case for all ~~long-term~~ models of long-term catchment deposition."

Critical Reviews in Environmental Control, 21(5,6):491–565 (1991)

...il to model future

1) Chemistry — chemistry of ppt of stream

biological geochemistry models

Appe...

Several ... including William ... (Hill and Wang, pub ... (Brown University P... Wildlands and Woo... Hanover, NH ... Vol. ...

this business in the bibliography on recommended reading

This ... past fores... general disc... below.

Sediment and Nutrient Retention by Freshwater Wetlands: Effects on Surface Water Quality*

Carol A. Johnston, Ph.D.

Center for Water and the Environment, Natural Resources Research Institute, University of Minnesota, 5013 Miller Trunk Highway, Duluth, MN 55811

* Contribution 77 of the Center for Water and the Environment.

ABSTRACT: Freshwater wetlands alter surface water quality in ways which benefit downstream use. This review summarizes the mechanisms of freshwater wetland interaction with sediment and nutrients that affect surface water quality. The mechanisms vary in magnitude and reversibility, and differ among wetland types. They include sedimentation, plant uptake, litter decomposition, retention in the soil, and microbial processes. Sedimentation is a relatively permanent retention mechanism whereby particulates and associated contaminants are physically deposited on the wetland soil surface. Plant uptake and litter decomposition provide short- to long-term retention of nutrients, depending on rates of leaching, translocation to and from storage structures, and the longevity of plant tissues. Plant litter can also provide a substrate for microbial processing of nutrients. Wetland soils sorb nutrients, and provide the environment for aerobic and anaerobic microorganisms that process nutrients. Wetland storage compartments, fluxes, and net retention rates are discussed for nitrogen and phosphorus.

KEY WORDS: wetlands, water quality, sediment, nitrogen, phosphorus, plants, litter, microbes, soil, retention.

...hat interact with contaminants ...mprove water quality ...ld,[1,2] but

Through tim... forest: disturbance s... of changes ranging fr... successional reclamatio... uncertainty as to what the ... region. However, consideri... probably existed and trees of ...

Chippewa Land Management Plan - Su...

what are they? why would they "probably" result from conditions in N. Wisconsin maybe in Q. specifically

...UATING APPROACHES TO THE CONSERVATION OF RARE AND ENDANGERED PLANTS[1]

...AS W. SCHEMSKE, BRIAN C. HUSBAND, MARY H. RUCKELSHAUS, ...OL GOODWILLIE, INGRID M. PARKER, AND JOHN G. BISHOP
...t of Botany, University of Washington, Seattle, Washington 98195 USA

...e choice is yours, don't ... —Nirvana

...00 species of vas... ...e extinct within ... vascular plant ... ...ly of conser... ...vation efforts ... of the En... ... §§ 1531– ... ...ed a legal ... ...mote the ... ...al infor... threat... ...covery ... and ... nec... ...S.C.

of genetic variation in rare plant species is a key consideration in conservation strategies," while Holsinger and Gottlieb (1991) note that "populations large enough to mitigate ecological threats to population viability will mitigate genetic ones as well" (1991:205) and that "active management of the genetic structure of an endangered plant species will require an enormous investment of time, money, and expertise. Only a few of the most important species will warrant such heroic efforts" (1991:206). With limited funds and such contrary points of view, the conservation biologist charged with species recovery faces an unenviable challenge.

The successful recovery of an endangered species requires the best scientific information available, yet the present level of understanding and communication among research scientists and resource managers is not sufficient to gather and transmit this information. Our objective in this paper is to integrate the theory of plant population dynamics and academic research on rare plants with the practical task of setting guidelines for species recovery.

First, we provide a general review of the ecological and genetic factors influencing demographic changes at population and metapopulation levels. Second, we review research on rare plants surveyed in the scientific literature and evaluate its usefulness in conservation. Third, we identify the biological information ... r developing ...

NUTRIENT MODEL

...model implemented for each g... ...ction.

...mary of Eval... ...s.. ... Re... ...d ... g and ...lic Hu... ...led P... ...ive Re...

long-term

... future

...d crude stream ... impacted by